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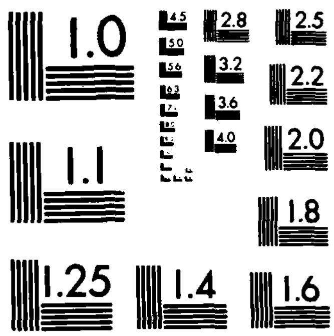

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Commercial and Military Communication Satellite Acquisition Practices

G. K. Smith, J. P. Stucker, E. J. Simmons

May 1985

Rand

PROJECT AIR FORCE

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This study tests the contention that the commercial sector consistently manages acquisition programs better than the military, by examining management practices and program outcomes associated with the acquisition of communication satellites by the Air Force and by the International Telecommunications Satellite Organization (INTELSAT). The study finds that the military and commercial programs are organized and managed in much the same way and that both produce well-functioning, useful spacecraft. Several significant differences in management practices and outcomes, however, suggest that the Air Force may be able to improve its acquisition activities. It concludes that, in carefully selected situations, there should be a place for the performance-oriented INTELSAT management practices.

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May 1985

A Project AIR FORCE report
prepared for the
United States Air Force

Rand
1700 MAIN STREET
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PREFACE

Most studies of weapon system acquisition management show wide latitude in defining what constitutes a successful or unsuccessful program; consequently, they can draw only limited conclusions concerning management effectiveness. However, occasionally both the military and the commercial sectors undertake to develop and procure similar products. In such cases, comparison of the methods and outcomes of the two programs provides an opportunity to assess at least the relative management effectiveness of each.

During the past decade the concurrent acquisition of communication satellites by the Department of Defense and by several commercial concerns offered an unusual opportunity for such side-by-side comparisons. In particular, the acquisition of technically advanced spacecraft by the International Telecommunications Satellite Organization (INTELSAT), which has been publicly documented in filings with the Federal Communications Commission, provides a close analog to some of the military communication programs.

This study compared the procurement of military communication satellites for the Defense Satellite Communications System programs with the procurement of commercial communication satellites for INTELSAT. The objective was to determine whether there are consistent and significant differences between the programs in terms of cost, schedule, and performance outcomes, and whether any such differences can be traced to different management practices. Finally, the study attempted to identify management practices that might aid military program managers in better controlling cost, schedule, and performance outcomes of future satellite acquisition projects.

This analysis of communication satellite costs was requested by the Director, Space Systems and Command, Control and Communications in the Office, of the Deputy Chief of Staff for Research, Development, and Acquisition, Headquarters United States Air Force. It was conducted as part of the "Analysis of Space Systems Costs" project within the Project AIR FORCE Technology Applications Program. The results should be of interest to Service and DoD personnel involved in the management of space system acquisition programs.

Data for this study were provided by INTELSAT and the Air Force Space Systems Division; however, the views expressed here are the authors' own and are not necessarily shared by INTELSAT or the U.S. Air Force.

Lt. Col. E. J. Simmons was an Air Force Research Fellow at Rand at the time of this study.

SUMMARY

A widespread "conventional wisdom" among critics of the weapon acquisition process contends that the commercial sector consistently manages acquisition programs better than the military. This study tests that contention by examining management practices and program outcomes associated with the acquisition of communication satellites by the Air Force and by the International Telecommunications Satellite Organization (INTELSAT). We find that the military and commercial programs are organized and managed in much the same general manner and that both produce well-functioning, useful spacecraft. Several significant differences in management practices and program outcomes, however, suggest that the Air Force may be able to improve its acquisition activities.

INTELSAT was chosen for the commercial side of this comparison because it is the leading procurer of commercial communication satellites. INTELSAT has sponsored the development of several different satellite models, each representing an important degree of technical advance over previously available models, and its contracts are a matter of public record through filings with the Federal Communications Commission. INTELSAT'S management practices, the type of spacecraft it acquires, and the subsequent operation of those spacecraft are sufficiently similar to the Air Force's requirements and practices that this comparison should be directly relevant to military managers.

FINDINGS

The principal findings of this study are that

- The general activities and approaches of the Air Force and INTELSAT satellite acquisition programs are surprisingly similar;
- But significant differences in management practices do exist;
- And we find some differences in program outcomes.

The following paragraphs discuss these topics.

Similarities

Despite the inevitable differences in system performance requirements between the military and commercial sectors, there are remarkable similarities in the management practices used by INTELSAT and the Air Force and in the success of their acquisition programs. Both organizations sponsor the development of technologically advanced systems and, after overcoming problems in the earlier designs, all of the products appear to be performing well and satisfying the customers.

Both organizations initiate their acquisition programs by awarding fixed-priced contracts to the winners of concept/design competitions. They both then change and amend the contract as the programs mature, in most cases adding additional spacecraft to the contracts, and at times negotiating follow-on contracts with the sole source producers. The two organizations specify their spacecraft performance and test requirements in similar fashion, and they both administer and oversee their acquisition programs through system program offices consisting of 60 to 70 people.

Because of differences in performance requirements—commercial satellites emphasizing communications throughput and military satellites emphasizing jam resistance and survivability—comparisons of price and performance are difficult. However, measured in terms of their individual specifications, almost all of the products seem to perform well on-orbit and earn nearly full performance incentives.

Our best opportunity to compare the price of completed systems was offered by the INTELSAT-IV and DSCS-II satellites. Both programs were started within a few months of each other and were similar in design and performance requirements. We estimate the price (exclusive of launch services) of the INTELSAT-IV satellites to have been $39 million per satellite in 1983 dollars and the price of the Air Force DSCS-II satellites to have been $35 million each.

Differences in Program Management

Looking beneath the surface similarities, however, we find some differences in management practices. INTELSAT uses firm-fixed-price contracts; bases its payments to the contractor solely on demonstrated progress in design, production, and delivery; and earmarks a substantial portion of the full acquisition price for performance payments, which are paid only when the satellites perform satisfactorily on-orbit. The Air Force, on the other hand, uses fixed-price-incentive contracts; pays a portion of design and production costs as they are incurred; pays the remainder (plus a contractual profit percentage) when end items are delivered; and uses cost incentives and award fees in conjunction with performance penalties which apply if the satellites do not perform satisfactorily in orbit.

The Air Force contracts are more detailed, containing many process specifications, data requirements, and references to external documents. By contrast, the INTELSAT contracts are self-contained and focus on specifying the end item, with few process specifications. Although more recent INTELSAT contracts are becoming more complex and detailed, they are still considerably less voluminous and complex than typical Air Force contracts. Finally, we observe major differences in personnel and management emphasis. INTELSAT draws on a fairly stable group of experienced professionals, expert in the ways of communication satellites, and stations the core of its support group near the contractor's plant to observe his technical progress, or lack thereof, first-hand and continuously. The Air Force's policy of rotating its career personnel results in less across-the-board technical expertise; and partly as a result of that, the Air Force project office concentrates more of its efforts on management of costs and processes than does INTELSAT. The Air Force DSCS program office remains at the Los Angeles Air Force Station regardless of the contractor's location.

In general, we might categorize the INTELSAT acquisition process as heavily performance oriented. The Air Force process is also primarily performance oriented, but in addition allocates significant activities to cost and process control. This different emphasis probably stems from the difference in staff experience and continuity in the two organizations and the fact that INTELSAT's chain of command is shorter, with the corporation's top management officials directly involved in most financial and many technical decisions.

Differences in Program Outcomes

Both organizations employ competitively awarded fixed-price contracts for their development and production activities, and both continually change those contracts as the programs progress. However, both the number and the dollar magnitude of the changes are considerably greater in Air Force programs than in comparable INTELSAT programs. Even in the INTELSAT-IV/DSCS-II comparison referred to above, where the final overall per-satellite price of the Air Force program was slightly lower than that of the INTELSAT program, the price growth for the Air Force system—defined as all increases in contract price except for incentives and the purchase of additional spacecraft—was 19 percent, compared with 2 percent for INTELSAT-IV. In the following generation of spacecraft, price growth accounts for about 10 percent of the INTELSAT-V contract and 25 percent of the DSCS-III contract.

DISCUSSION

The INTELSAT approach to satellite procurement—emphasizing delivery and performance—is characteristic of commercial practices. Corporations procure equipment to generate revenue, and they want that equipment to be delivered on time, at the agreed price, and they expect it to work immediately. Late delivery or faulty performance reduces profits. INTELSAT, in conducting its business of worldwide satellite communications, makes major procurements involving both satellites and ground equipment, and has developed an extensive and sophisticated organization to manage such procurements.

Air Force acquisition practices, on the other hand, have evolved in response to the generalized environment that surrounds most large governmental purchases. The Air Force buys many diverse types of costly, sophisticated equipment and must constantly reassess its possibilities and priorities in response to changes in technologies, intelligence concerning its need for various systems, and its budget. In particular, the size and composition of the overall Air Force acquisition budget ensure that communication satellites are seldom given top priority for dollars or for management overview.

In this environment, it is unreasonable to expect military satellite acquisitions, even when well thoughtout and fully specified at the time of contract award, to proceed smoothly and without change. Furthermore, management practices that attempt to lock in initial specifications and schedules such as multi-year or full-package procurement, may actually hinder attainment of the wider, constantly evolving needs of the Service.

Nevertheless, in carefully selected situations, there should be a place for the performance-oriented INTELSAT management practices. In acquisitions where the requirement is firm and the mission is important enough to escape routine rebudgeting actions, contracting methods that emphasize performance, such as firm-fixed-price contracts and achievement-based progress payments, can work as well for the military as they have for INTELSAT.

ACKNOWLEDGMENTS

This project was initiated by Dr. Patricia Dinneen. Her early direction and contributions set high standards that remained challenging throughout the study.

This project could not have been completed without the extensive assistance generously provided by personnel in INTELSAT and the Air Force. We are especially indebted to Mr. Peter Ferrandino, Director of Procurement for INTELSAT, in helping us to understand and interpret the various INTELSAT programs. Mr. Martin Votaw, project manager on the INTELSAT-III and -IV programs, and Mr. Ralph Scott, project manager on the INTELSAT-V and -VI programs, also provided valuable information and assistance in understanding those programs. Capt. Gary Rusnak and Lt. Paul V. Borish of the Air Force DSCS project office, and Mr. Jack Martin of the Air Force Plant Representative Office at TRW, were most helpful in providing documents and general assistance in our analysis of the Air Force programs. Mr. Alfred Fisher, head of the configuration management office in the DSCS SPO, and Mr. Albert Finney, manager of the Aerospace Corporation team supporting the DSCS development phase, were also very helpful.

We are also indebted to our Rand colleague, Dr. Kenneth A. Solomon, for his analysis of the Air Force and INTELSAT test programs.

Despite this considerable assistance, the authors remain fully responsible for the conclusions of the study and for any errors or misinterpretations of fact that may appear.

CONTENTS

FIGURES

TABLES

GLOSSARY

AFSATCOM	Air Force Satellite Communications System
AMIS	Acquisition Management Information System
ASME	American Society of Mechanical Engineers
CDRL	Contract Data Requirements List
COMSAT	Communications Satellite Corporation
CPFF	Cost plus fixed fee (contract)
dBW	Decibels above 1 watt, a measure of signal strength
DAR	Defense Acquisition Regulation
DBS	Direct (television) broadcast satellite
DCA	Defense Communication Agency
DID	Data item description
DoD	Department of Defense
DSCS	Defense Satellite Communications System
EIRP	Effective isotropic radiated power, a measure of the signal strength radiated by a satellite to the earth; it is based on a combination of transmitter and amplifier power and effectiveness of the antenna beam concentration
eol	End of orbital design life
FCC	Federal Communications Commission
FPI	Fixed price incentive (contract)
FFP	Firm fixed price (contract)
Ford	Ford Aerospace and Communications Corporation
F-n	Flight spacecraft number n
GAO	General Accounting Office
GE	General Electric
GHz	Gigahertz (billion cycles per second)
GFE	Government furnished equipment
Hughes	Hughes Aircraft Company
jle	Jammer-locator electronics
IDCSP	Initial Defense Communications Satellite Program (DSCS-I)
IDSCS	Initial Defense Satellite Communications System
INMARSAT	International Maritime Satellite Organization
INTELSAT	International Telecommunications Satellite Organization
ISAT-n	Designation used in this report for INTELSAT satellite systems
IUS	Inertial Upper Stage (booster)
kW	Thousands of watts of primary power
lvf	Launch vehicle failure
MCP	Maritime communications package
MHz	Megahertz (millions of cycles per second)
NASA	National Aeronautics and Space Administration
na	Table entry indicating an item is not applicable
ni	Table entry indicating no information is available concerning an item
nps	Not priced separately
Philco	The Western Development Laboratories Division of Philco-Ford, later called the Ford Aerospace and Communications Corporation
SCT	Single-channel transponder
so	Table entry indicating a spacecraft is still operating satisfactorily
SPO	System Program Office

STS	Space Transportation System (basically the space shuttle)
s/c	Spacecraft
TRW	TRW, Inc.
TWT	Traveling-wave tube (used in satellite radio-frequency amplifiers)
TWTA	Traveling-wave-tube amplifier
w	Watts
wnl	Table entry indicating a spacecraft was not launched
+−	Plus or minus

I. INTRODUCTION

In the competitive world of commercial products the marketplace provides a ready measure of management effectiveness. Well-managed firms generally make profits, others incur losses. Unfortunately, there is no equivalent measure of management effectiveness in weapons system acquisition. Short of war, analysis and evaluation of the management of weapons system acquisitions have always been limited by the lack of clear-cut utility criteria.

Occasionally it is possible to find a military product that has a close analog in the commercial market, and then to compare product price, schedule, and performance between the military and commercial versions, and to draw inferences regarding the relative effectiveness of the two sectors' acquisition management practices. Several studies have compared military and commercial transport aircraft.[1] Another comparison now is possible since both sectors have developed and put into operation communication satellites. Although there have inevitably been differences in the design and performance specifications of the satellites, there are enough similarities between contemporary programs to justify at least rough comparisons of management effectiveness.

An initial attempt to compare the effectiveness of commercial and military satellite procurements was made by the General Accounting Office (GAO) in 1979. That study, focusing on the cost and schedule experience of military and commercial communication satellites, found that

> The average costs to develop, procure, and launch the military's latest generations of communications satellites have been greater than the most expensive commercial satellites. The military's higher costs have been the result of (1) more sophisticated satellite designs, (2) more costly developmental programs and (3) developmental schedule delays that require alternative satellite procurements for operational "gapfillers."
>
> ...the latest military satellite developments have been technically difficult and, consequently, harder to manage. In contrast to the military experiences, the commercial sector's lower costs have resulted from more conservative and, therefore, more manageable satellite developments.[2]

The report goes on to note that military programs generally experienced somewhat higher cost growth than comparable commercial programs:

> Unplanned for cost growth in the military contracts have ranged from 15 to about 238 percent over the original prices. In contrast to the military, the highest cost growth for this type in any commercial contract was about 11 percent.... In general, it appears that the military's cost growth results mainly from development-related overruns.
>
> ...the figures indicate the military's optimism, with respect to costs, during the initiation periods for each program. Consequently, decisionmakers may have not appropriately considered the potential costs for each program.

Although the GAO clearly noted that military satellites generally had performance requirements exceeding those of contemporary commercial systems, and that the performance

[1]See, for example, *1980 Commercial Practices Program*, Headquarters, United States Air Force Systems Command, January 1981, and *Commercial vs. Military Practices: A Discussion for System Acquisition Considerations*, Defense Science Board Summer Study on Reducing the Unit Cost of Equipment, August 1981.

[2]*Relative Performance of Defense and Commercial Communications Satellite Programs*, GAO report LCD-79-108, August 1979.

differences were a major contributor to cost and schedule differences, the overall tone of the report was critical of military acquisition practices. That tone was consistent with a widespread "conventional wisdom" among critics of the weapon acquisition process that the commercial sector manages acquisition programs consistently better than the military does and that, if the Defense Department could somehow adopt some of the management practices followed by the commercial sector, military costs could be reduced substantially.

STUDY OBJECTIVES

This study was designed to accomplish three broad objectives. First, to test the hypothesis that management effectiveness differs between commercial and military programs. Second, to identify specific relevant management practices, and determine if these practices could be beneficially adopted by military managers. And third, to update the public data base of program characteristics for commercial and military communication satellites and to publish that data in a widely available form so that it can be used by other students of the acquisition process.

To link differences in program characteristics with identifiable management practices it is necessary to study programs in detail, and to examine commercial and military products that are generally similar. With these considerations in mind, we elected to compare the acquisition of communication satellites for the Air Force's Defense Satellite Communications System (DSCS) with the acquisition of similar satellites by the International Telecommunications Satellite Organization (INTELSAT). Each of these families of satellites has evolved over the past two decades under a reasonably consistent acquisition management philosophy, and each comprises a series of increasingly large and sophisticated designs. Thus a comparison of the two organizations, their management approaches, and the outcomes of their programs should yield useful insights into the relative effectiveness of those management approaches.

INTELSAT was, and to a major extent remains, the pioneering agent in commercial satellite communications and offers special advantages for our commercial/military comparison. From 1965 until recently, it held a virtual monopoly on commercial satellite communications between nations while at the same time providing domestic services to individual countries. Its market power has eroded somewhat in the past few years as a number of firms have initiated competing domestic and "regional" services, and several are now challenging its privileged international position.

Still, INTELSAT continues to be the leading developer and procurer of advanced commercial satellites. The newer, and smaller, commercial firms, by contrast, purchase mainly production models of satellites that have already been developed by others (the Air Force, INTELSAT, NASA, or the manufacturers themselves). Few of these firms have more than a short history of satellite procurement, and all that we contacted were reluctant to provide information for publication. INTELSAT, on the other hand, satisfies all of our criteria for the commercial/military comparison: it has sponsored development of several different satellite models, each representing an important degree of technical advance over then-available models, and its contracts are a matter of public record through filings with the Federal Communications Commission. In addition, the INTELSAT personnel were gracious in sharing their time and knowledge.

The DSCS and INTELSAT satellite series display general similarities, but there are important differences that affect detailed system comparisons, especially of price and performance. Each organization launched its first satellite at about the same time (INTELSAT in

1965 and DSCS in 1966[3]), but the INTELSAT series to date includes six different models, whereas the DSCS series includes only three models. Furthermore, there are important differences in the performance requirements between the military and commercial systems. For some parts of the analysis those differences are relatively unimportant. In other parts (e.g., comparison of actual costs) the differences are important, and there we limit the comparisons to the most similar systems.

GENERAL APPROACH

We first examine the *acquisition practices* of the various projects, with emphasis on identifying similarities and differences between the two organizations.
We then examine the *outcomes* of these projects to see if there were any systematic and important differences between the military and commercial programs. Four types of outcomes are examined:

1. *On-orbit lifetime.* In general, communication satellites either work pretty much according to specifications, or they fail completely. We measure the overall performance of each system by determining how long the satellites functioned satisfactorily in their space environment.
2. *Development schedule.* We compare the actual time required to develop the various satellites, and how much the development schedules slipped from their original program specifications.
3. *Satellite price.* We compare consistently derived estimates of satellite price—that is, the total project price divided by the number of satellites produced.[4]
4. *Program price growth.* We examine the difference between initial contract price and the eventual full price of the programs. For the ISAT-II[5] through -IV/A and the DSCS-II programs we have good information on full program prices. The ISAT-V and DSCS-III programs are still active and we must depend more on estimates and projections.

After briefly describing of the DSCS and INTELSAT organizations and their satellite programs in Sec. II, we examine acquisition practices. The major characteristics of the contracts that the Air Force and INTELSAT use to acquire their communication satellites are described in Sec. III, as are the management teams that oversee and enforce those contracts. Section IV discusses the incentives written into the contracts to promote cost control, schedule promptness, general management effectiveness, and the ultimate on-orbit performance of the satellites.

---

[3]The first DSCS satellites were launched in 1966 as part of what was then called the Initial Defense Communication Satellite Program (IDCSP).

[4]Although it is common to talk about program *cost*, this study concentrates solely on the *price* of these systems. This is a necessary distinction because we only have information on the payments from INTELSAT and the Air Force to the several suppliers of spacecraft and launch services. We do not know how much any of the items actually cost, either to the suppliers (since they were usually not required to report their costs to INTELSAT under their fixed-price contracts) or the nation. In several cases, however, it is widely believed that the contractors spent more on development and the initial production lots than they recovered through the contracts.

The "as of" date for all estimates is as close to September 30, 1983, as was feasible. Dates for individual estimates are reported in the text and appendixes. For the currently open programs, no changes after September 1983 have been incorporated into any estimates.

In the appendixes we occasionally differentiate between development and production prices, but the data did not allow this breakdown to be made consistently.

[5]For brevity, the name INTELSAT will be abbreviated to ISAT when referring to satellite designations.

With the material on management practices as background, we turn our attention to program outcomes. Section V examines the actual outcomes of the DSCS and INTELSAT programs and attempts to relate those outcomes to particular management practices; Sec. VI presents the conclusions of the study. Details on cost analysis methodology and data are included in the appendixes.

II. AN OVERVIEW OF THE DSCS AND INTELSAT SYSTEMS

Although the primary purpose of both commercial and military communication satellite systems is to facilitate the reliable transfer of information from one earth-based user to another, the detailed goals of the two systems, the conditions under which they must operate, and their procuring and operating organizations differ somewhat. The following general overview of the INTELSAT and DSCS programs provides a context for the subsequent comparisons and interpretations. Details of the technical attributes and costs of individual systems are given in Apps. A and B.

THE INTELSAT SYSTEM

INTELSAT consists of 108 partner nations that operate as a financial cooperative. The members of INTELSAT are the governments of those nations or their designated telecommunications entities. COMSAT, a for-profit corporation with more than 8 million shares outstanding, is the U.S. designate.

Currently, about two-thirds of the world's transoceanic communications travel via INTELSAT satellites which are maintained in geostationary orbits, 22,300 miles above the equator. The July 1983 constellation consisted of 15 satellites in orbit. Six satellites were carrying priority traffic (three over the Atlantic Ocean, two over the Indian, and one over the Pacific), four were contingency spares, three more were retained because they had some residual capacity, and two were retired. The spares, which may carry lower-priority traffic or be leased for domestic communication services, usually are older satellites (some of which may have suffered degradation in performance) or new satellites that have not yet been activated.

INTELSAT is currently procuring its sixth generation of communication satellites. The separate systems are known as: ISAT-I (or Early Bird); ISAT-II; ISAT-III; ISAT-IV and -IVA; ISAT-V and -VA; and ISAT-VI. The -IVA and -VA designations refer to follow-on buys of spacecraft in which the communication capability differed significantly from that of the spacecraft procured in the original contracts.

The satellites in use by INTELSAT at any one time represent several generations of satellite technology. For example, in July 1983 the Atlantic Ocean configuration consisted of an ISAT-IVA and two ISAT-Vs in service, and an addition -IVA and -V on-station as contingency spares.[1]

THE DSCS SYSTEM

DSCS is under the operational control of the Defense Communication Agency (DCA); the acquisition and launch of satellites are handled by the Space Division (SD) of the U.S. Air Force Systems Command. The primary purpose of DSCS is to provide highly reliable and secure command and control communications to overseas elements of the U.S. Department of Defense (DoD). It also provides secure communications to the U.S. Department of State and its Diplomatic Missions. The system is designed to remain functional at all levels of tactical

[1]Two other less serviceable ISAT-IVs and one -V were available on-station with some residual capacity for leased service and testing, and two retired -IVs were still in geostationary orbit.

and strategic warfare, except for a direct attack against on-orbit satellites.[2] During peacetime, DSCS carries over half of all DoD overseas telecommunications traffic.

DSCS satellites communicate to hundreds of different stations, including fixed and transportable earth stations, aircraft, and ships. These stations have been developed by the individual military services to satisfy specific combat requirements. No common standard was used in the development of these stations, so the burden falls on the satellite to accommodate their capabilities. Unfortunately, transportable earth stations and aircraft tend to have smaller antennas and far less power available than do fixed earth stations, placing demands on DSCS satellites not shared by commercial satellites.[3]

The DSCS system is procuring and deploying its third generation of satellites. DSCS-II and -III satellites are deployed over four geographical regions: the Indian Ocean, the Western Pacific, the Eastern Pacific, and the Atlantic.

SUMMARY OF PROGRAM CHARACTERISTICS

Table 1 summarizes some of the main characteristics and operational parameters of the six INTELSAT and three DSCS programs. This information has been taken from a number of sources and is believed to be reasonably current and correct.

Note that the DSCS and INTELSAT systems cover essentially the same time span, although the INTELSAT system contains about twice as many models. ISAT-I, or Early Bird, was the first commercial communication satellite launched, and one of the first geostationary satellites. The first IDCSP,[4] or DSCS-I, was launched about a year later.

Hughes Aircraft, clearly the leader of the Western world in satellite production, designed and manufactured five of the 11 systems shown in Table 1. The Western Development Laboratories of Philco-Ford produced IDCSP, and later, as Ford Aerospace and Communications Corporation, produced the ISAT-V and -VA. TRW and General Electric are also experienced satellite suppliers.

Commercial communication satellites operate in two frequency bands: the 6/4-GHz frequency pair[5] has been used since Early Bird was launched in 1965, and the 14/11-GHz band has been employed since the late 1970s. The higher frequencies offer advantages in greater capacity and smaller antenna size for the same signal strength. At the same time, electronic components for the 14/11-GHz range tend to cost more and the shorter wavelength demands

[2]That is, it is designed to survive nuclear attacks against other spacecraft, and against the satellite control stations.

[3]Direct broadcast satellites (DBS), beaming TV signals to private roof-top antennas, are beginning to change this situation. One-hundred watt transponders have been launched and 200-watt DBS satellites are expected in 1986.

[4]After this system was declared operational in 1968, its name was changed to the Initial Defense Satellite Communications System (IDSCS).

[5]The first number is the frequency of the signal traveling from the ground to the satellite—the uplink. The second number is the frequency of the downlink—the signal traveling from the satellite to the ground. The use of two frequencies allows both ground stations and satellites to simultaneously receive and transmit without interference. The frequency bands are often referred to by alternative terms. For example,

Frequency Pair	Band	Range	System
0.3/0.2 GHz	S-band	UHF	DSCS-III (SCT)
1.6/1.5 GHz	L-band	UHF	ISAT-V (MCP)
6/4 GHz	C-band	SHF	ISAT-I, . . . ,VI
8/7 GHz	X-band	SHF	DSCS-II,III
14/11 GHz	Ku-band	SHF	ISAT-V,VI

Table 1

MAJOR CHARACTERISTICS OF THE DSCS AND INTELSAT SATELLITE PROGRAMS

Item	DSCS Programs -I	DSCS -II	DSCS -III	INTELSAT Programs -I	INTELSAT -II	INTELSAT -III	INTELSAT -IV	INTELSAT -IVA	INTELSAT -V	INTELSAT -VA	INTELSAT -VI
General											
First launch (date)	6/66	11/71	10/82	4/65	10/66	9/68	1/71	9/75	12/80	(85)	(86)
Design life (years)	1.5	5	10	1.5	3	5	7	7	7	7	10
Power, solar (kW @ eol)	0.04	0.36	0.83	0.03	0.07	0.13	0.46	0.53	1.15	1.15	2.15
Weight (lb)	100	1300	2500	85	190	330	1600	1900	2200	2600	4000
Body stabilization	spin	spin	3-axis	spin	spin	spin	spin	spin	3-axis		spin
Prime contractor	Philco	TRW	GE	Hughes	Hughes	TRW	Hughes	Hughes	Ford		Hughes
Communications capability											
Frequency (up/down, in GHz)	8-7	8-7	8-7	6-4	6-4	6-4	6-4	6-4	6-4/14-11		6-4/14-11
Transponders (# active)	1	2	6	2	1	2	12	20	12/10		40/8
Bandwidth (MHz)	20	50-185	60/85	25	126	225	36	63	36-241		36/150
Frequency reuse	no	no	yes	no	no	no	no	yes	yes		yes
Power, output (EIRP in dBW)	7	31	29	10	15	27	22	22	22/25		24/na
Capacity (2-way voice circuits)	11	2000	2200	240	240	1500	3750	6000	12,000	15,000	40,000
Program prices (millions of 1983$):											
Spacecraft (including incentives)	115	555	620	36	60	177	309	244	677		613
Launch	0	408	331	17	65	134	352	247	620		275
Total program	115	963	951	53	125	311	661	491	1297		888
Performance											
Design											
Spacecraft purchased (#)	37	16	7	2	5	8	8	6	9	6	5
Price per S/C (million 1983$)	3	60	136	27	25	39	83	82	86		178
Possible circuit months (1,000s)	7.3	1920	1848	8.6	43.2	720	2520	3024	9072	7560	24000
Price per circuit-month (1983$)	16000	500	500	6000	10000	450	250	150	80		40
Actual											
S/C successfully operated	26	>11	na	1	3	5	7	5	na		na
Price per S/C (million 1983$)	4	<88	na	53	42	62	94	98	na		na
S/C-months of operation	ni	>400	na	45	84	133	>559	>353	na		na
Total circuit months (thousands)		>800	na	10.8	20.2	199.5	>2096	>2118	na		na
Price per circuit-month (1983$)		<1200	na	5000	6000	1500	<300	<250	na		na

SOURCE: Technical information was taken from D. H. Martin, M. P. Brown, Jr., INTELSAT, and A. F. Space Division; costs are from Tables A.15 and B.13.

NOTE: Price estimates represent complete program prices for ISAT-I, -II, -III, IV, and IVA, and estimates as of September 1983 for ISAT-V and -VA, -VI, DSCS-II, and -III. Price for DSCS-I (IDCSP) is for spacecraft payments only. The symbols "<" and ">" are used with current systems to indicate that performance may increase as time passes, reducing the several measures of price per unit. EIRP measures the power output of an earth-coverage beam. Dual entries for bandwidth and power indicate either a combination or range of values (-) or that different values are associated with the different frequency ranges.

"ni" indicates that no information is available concerning an item.

"na" indicates that an item is not applicable because the system is just beginning (or has not yet begun) operations.

more precise antenna pointing, thus increasing requirements on satellite attitude control systems.

DSCS satellites use the 8/7-GHz band for primary communications. For the same power and signal-to-noise requirements, 8/7-GHz electronics generally to cost more than 6/4-GHz devices, but less than those that operate at 14/11 GHz. Similarly, 8/7-GHz systems lie between 6/4-GHz systems and 14/11-GHz systems in terms of demands on antenna pointing accuracy and attitude control systems, and, therefore, on satellite weight.

In Apps. A and B to this report we construct the full, on-orbit price of each INTELSAT and DSCS system, including all that was spent on (1) spacecraft and equipment,[6] (2) launch vehicles and launch services, and (3) on-orbit performance incentives.[7] As these contracts will, if DSCS-III and ISAT-VI follow the normal pattern and operate for their full design life, cover more than 30 years of constantly inflating prices, we also transform the prices for all the systems into common 1983 dollars.[8]

Table 1 shows the cost per unit of communication capacity of each satellite system. This measure dramatically indicates the continuing advances in communications and manufacturing technology, especially for the INTELSAT satellites. The first major advance was with ISAT-III, increasing cost effectiveness three- to four-fold over ISAT-I and -II. The ISAT-IV/IVA series then lowered the cost-per-circuit of ISAT-III by a factor of about five. More recently, ISAT-V will probably triple the capacity of ISAT-IVA, and ISAT-VI, if it operates successfully on orbit, should at least double the capacity of ISAT-V.

The DSCS prices and communications effectiveness should not, in general, be compared with the INTELSAT measures because of differences in design and function. The design of military satellites trades off a large portion of its potential communications capacity in return for nuclear hardening and antijam capabilities that are not found on commercial systems.[9] In some cases, however, careful comparisons are possible and rather interesting—Sec. V discusses detailed comparisons of the DSCS-II and the ISAT-IV and IVA systems, and to a lesser extent the DSCS-III and ISAT-V systems.

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[6]These prices take into account cost and schedule penalties and award fees.

[7]For the systems still operating or in development we estimated the value of full (maximum) on-orbit incentives.

[8]The spacecraft escalation factors and the alternative factors used in sensitivity testing are discussed in App. D.

[9]Also note that in both the INTELSAT and the Air Force programs launch cost is a large portion of the total space segment price; in addition, the Air Force is not charged consistently for launch-associated items—many are charged to launcher research and development accounts rather than to the satellite accounts. Hence the ratio of launch price to spacecraft price varies widely within military systems and the total system costs of the DSCS systems are not directly comparable with those of the INTELSAT systems. Launch costs are discussed in greater detail in Apps. A and D.

III. COMPARISON OF ACQUISITION PRACTICES: CONTRACTS AND PROGRAM ORGANIZATION

The primary objective of this study is to determine if differences in outcomes, such as system cost and reliability, between military and commercial communication satellite programs can be accounted for by differences in acquisition practices; and in doing so, to identify commercial practices that might beneficially be adopted by military acquisition managers. In this and the next section, we describe our comparison of the management structure and acquisition practices of the Air Force and INTELSAT satellite procurement organizations.

CONTRACT TYPES

Almost all of the projects considered in this study were conducted under some form of fixed-price contract.[1] The contracts used by the Air Force used fixed-price-incentive (FPI) contracts, which include a cost or price incentive as well as the customary schedule and performance incentives. A FPI contract, specifies a target cost and an associated target price. If the contractor incurs costs above the target cost, the Air Force shares those extra costs up to some ceiling level, above which all additional costs are borne solely by the contractor. Thus the Air Force shares some of the cost risks with the contractor. Details of those cost incentives are furnished in Sec. IV.

INTELSAT used a firm-fixed-price (FFP) contract in almost all procurements.[2] In this form of contract, a basic price is agreed upon for some specified set of services and products, and that price is not modified by any change in the costs incurred by the contractor. In fact, actual costs are not identified as a contract parameter. The final contract price may, however, be modified by schedule or performance incentives.

In every program examined in this study, the initial contract was signed in a competitive environment with at least two qualified contractors competing for the business. Every program also involved follow-on procurement of spacecraft, sometimes through contract changes and sometimes through supplementary contracts. The follow-on procurements were also FPI or FFP, and they were always negotiated with the single supplier that had already completed at least some portion of the project.

CONTRACT CHANGES

The use of fixed-price contracts does not mean that the entire program was completed for the price specified in the original contract. All of the programs underwent considerable change and extension beyond the original contract. But were there differences between military and commercial programs in the frequency and magnitude of program changes? We attempted first to simply count the number of changes in each program, but that proved unsatisfactory. There were too many different kinds of change not treated consistently by the two organizations:

[1]The exception was a single cost-plus-fixed-fee (CPFF) line item added to the DSCS-III production contract to cover integration of the spacecraft with boosters not specified in the original contract.

[2]The exception was a FPI amendment procuring four follow-on ISAT-IV spacecraft (see Sec. IV).

- Design changes to extend system capability (typically initiated by the buyer, and normally leading to price changes).
- Design changes to exploit new technology (some of which resulted in price changes, others did not).
- Design changes to correct deficiencies in the original design (the cost of which was usually, but not always, absorbed by the seller).
- Changes in delivery schedule (caused by a variety of events, sometimes leading to price changes and sometimes not).
- Procurement of additional spacecraft.
- Purely administrative changes in contract language, many of which were little more than legal technicalities and rarely involved price changes.

The administrative procedures of INTELSAT and the Air Force also differ. INTELSAT tends to accumulate a number of changes into each contract modification, resulting typically in one to two dozen contract changes throughout the life of a program. The Air Force tends to treat each event as a separate contact modification, often resulting in several hundred contract changes in each program. The enumeration problem was further confounded by the fact that in some programs new contracts were issued for the procurement of follow-on spacecraft *and* for design improvements, without any clear distinction between the price of the recurring and nonrecurring activities.

The only method of comparison that could be uniformly applied to both INTELSAT and Air Force programs was price change. Table 2 shows the extent by which the final contract price exceeded the original price in each program. Because much of that price change was attributable to procurement of additional spacecraft, the number of spacecraft in the original and final forms of each contract is also shown.[3]

It is clear that in all of the programs the original contract, reached in a competitive environment, covered only a portion of the eventual program scope. The remaining portion, consisting of contract changes and follow-on contracts that were all negotiated with the sole source, is growing in both INTELSAT and the Air Force.

CONTRACT ORGANIZATION

In style and organization, Air Force and INTELSAT contracts have some similarities and some differences. Similarities are strongest in how system performance and tests are specified. Differences in the two organizations' contracts follow in part from the different legal requirements imposed on government and commercial buyers, the way each buyer has interpreted those legal requirements, and the different staffing arrangements used by the Air Force and INTELSAT.

Satellite Specifications

An examination of INTELSAT and DSCS satellite specifications shows much similarity in both type and intent in the specification of system performance and of the testing programs. The most significant similarity is in the specification of the payload portion of the spacecraft. This is not surprising because the missions of both DSCS and INTELSAT revolve around delivery of a payload. To demonstrate this similarity, several quotes from the satellite

[3] A more thorough discussion of each contract and the changes made is contained in the appendixes.

Table 2

CHARATERISTICS OF MAJOR INTELSAT AND DSCS CONTRACTS

Program	Contract Date	Contract Type	Primary Deliverables in the Initial Contract	Additional Satellites	Price Change (percent)
ISAT-III	5/66	FFP (competitive)	Full system development, build 6 flight satellites	2	47
ISAT-IV	10/68	FFP (competitive)	Full system development, build 4 flight satellites	4	48
ISAT-IVA	4/73	FFP (sole source)	Modify original design, build 3 flight satellites	3	71
ISAT-V	9/76	FFP (competitive)	Full system development, build 7 flight satellites	8[a]	147[b]
ISAT-VI	4/82	FFP (competitive)	Full system development, build 5 flight satellites	0	(c)
DSCS-II initial	2/69	FPI (competitive)	Full system development build 6 flight satellites	0	25
DSCS-II replenishment	10/74	FPI (sole source)	Procurement of 6 flight satellites	4	171
DSCS-III development	1/77	FPI (competitive)	Full system development, build 2 flight demonstration satellites	0	126
DSCS-III refurbishment	10/80	FPI (sole source)	Long-lead items	1	408
DSCS-III production	10/80	FPI (sole source)	Long-lead items	4	630

SOURCE: Tables C.3 through C.6 and B.3 and B.4.

[a]Last six satellites were designated ISAT-VA.

[b]This contract is still open, and additional orders may be placed.

[c]Initial phase of contract is still under way. Experience is insufficient to identify the final price.

specifications are listed below. After each quote, the satellite specification and page number are listed in parentheses.

> *Gain Stability.* Over a 30 day interval, the combined effects of antenna variation due to pointing variations, and of transponder gain variations due to seasonal thermal variations, telemetry usage, earth coverage EIRP variations between 25 and 28 dBW and narrow coverage EIRP variations between 36 and 43 dBW shall not exceed 1.2 dB peak-to-peak for channels 1 and 4, and 2.0 dB peak-to-peak for channels 2 and 3. Both narrow coverage and area coverage beams shall be switchable by command such that signals received by the "off" antenna beam shall be attenuated by at least 30 dB. (DSCS-II, p. 20).

> *Gain Stability.* The change of gain at the center frequency of each transmission channel, including the antennas, shall not exceed +-1 dB over any operating day, and +-2 dB total over the operating lifetime. The specified long term stability shall include any errors in initial gain setting. The transponder design shall not utilize automatic gain control in order to meet the above requirements.

The above specification shall be met over any day without the use of gain command. However, gain command may be employed if required to meet the gain stability over the satellite lifetime.

The change in gain flatness is defined as the residual change in frequency response after subtracting the gain change at the center frequency of the transmission channel. This change shall not exceed 0.5 dB peak-to-peak over the usable bandwidth of the transmission channel. This specification applies over the lifetime as well as over any operating day, measured at any fixed point in the operating beamwidth of the antenna. (ISAT-IV, p. A-10).

* * * * *

Communications EIRP. The EIRP of the single retransmitted signal in channels 1 or 2 to any point within earth coverage shall exceed 31 dBW. The EIRP of the single retransmitted signal in channels 3 or 4 to any point within the coverage of the narrow beam powered alone, and when both beams are powered, shall exceed 40 dBW for the focused beam and 33 dBW for the defocused beam (25%/75% power split). EIRP of the defocused beam on-axis and powered alone shall exceed 45.0 dBW. The maximum EIRP of the earth coverage beacon anywhere within the earth coverage shall be a minimum of −18 dB with reference to the maximum signal power. The earth coverage beacon level shall be capable of being switched by command from maximum beacon power to a level 12+−3 dB below maximum and to an off condition. The above specifications shall be met with the channel gain control set anywhere between midrange and the high gain condition and with an incident power level on the satellite of −74 dBm on the edge of the respective antenna coverages and after deducting losses attributable to the earth coverage beacon, antenna pointing errors, satellite attitude, orbit inclination and predicted component aging for operational life. For channels 3 and 4, the above EIRP specification values shall apply only under the condition of narrow coverage beacon "off." (DSCS-II, p. 19).

Equivalent Isotropically Radiated Power (EIRP). The EIRP per transmission channel under conditions of single carrier saturation measured at any frequency within the usable beamwidth as described in Paragraphs 3.5.1.1 and 3.5.2.5 respectively, (satellite illuminated as per Table A.2) shall be equal to or higher than the values stated in Table A.4. (Table A.4 has values in dBw for the EIRP for global and spot beams.) (ISAT-IV, p. A.6).

The above quotations contain different language, but show a similar intent and level of detail. Similar intent and level of detail are also seen in aspects of the testing, inspection, and quality assurance parts of the military and commercial programs.

Each system or subsystem or element is tested under the guidance of a test matrix. Typically, along the vertical columns are the performance criteria being tested (e.g., electrostatic susceptibility, leak, drainage) and down the horizontal columns are the tests themselves (e.g., vibration, thermal stress, acceleration). Both the performance criteria and the test themselves are specified, to varying extent, in the Military Specifications, Military Standards, American Society of Mechanical Engineers (ASME) codes, and other documentation.

Table 3 compares the INTELSAT and Air Force component acceptance testing programs by categories of components and categories of tests. It divides components into several categories, then sorts through a number of component types that fall into each of these categories and determines test categories that are required, optional, or not required. Although this breakdown is not unique (e.g., some components may fall into two or more categories) or complete, it provides a means for understanding the general nature of tests required on groups of similar components. The table demonstrates a basic trend—most tests that are required by one program are also required by the other.

There are, however, important differences in other sections of the specifications. For example, the DSCS-III specification contains four pages devoted to design and construction of the satellite and include references to many Military Specifications and Military Standards.

Table 3

COMPONENT ACCEPTANCE TEST COMPARISON

COMPONENT ACCEPTANCE TEST COMPARISON																						
Test	Electrical		Antennas		Mechanical		Solar Panel		Batteries		Valves		Fluid Propulsion Equipment		Pressure Vessel		Thrusters		Thermal Equipment		Optical Equipment	
	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V	DSCS-III	INTELSAT-V
Functional	R	R	R	R	R	R	R	R	R	R	R		R		R		R		R		R	
Thermal Vacuum	R	R	O	R	R		O	S	R	R	R	R	R		O		R		R		R	
Thermal Cycling	R	R	O		O	S	O	S	O		O	R	O									
Random Vibration	R	R	R	R	R	S		S	O	R	R		R		O		R		R		R	
Acoustic	O		R				O			R												
Pyro Shock	O	S																			O	
Pressure					O				R	R	R	R	R	R	R	R	O		O		O	
Leak	R				R				R	R	R	R	R	R	R	R	O					
Burn-in	R	R			O	R					R						R					
Final Performance		R		R		R		R		R		R										

Legend: R = Required
O = Optional
S = For some of the components

INTELSAT-V (upper right) / DSCS-III (lower left)

INTELSAT contracts are largely silent on these details. A short quote from the DSCS-III specification follows:

> Lubricants. Lubricants shall not be exposed to outgassing products which are incompatible with the lubricant.
>
> Lubrication of rolling element bearings shall meet the requirements of GE specification 171A4696 unless otherwise specified herein. . . .
>
> Fungus Resistance. The use of materials which are classified as fungus nutrient materials according to MIL-STD-454D shall be avoided to the maximum extent possible. When the use of such fungus nutrient materials is contemplated, the material must be accepted in drawing number 490L230, DSCS III Approved Materials and Processes List, on the basis of either previous program acceptability or test per the requirements of MIL-STD-454D. (DSCS-III, p. 3-61 through 3-64).

The same four pages of the DSCS-III specification also contain details on polymer materials, dissimilar metals, corrosion resistance, propellant compatibility, system grounding, shielding and bonding, connectors, wire harnesses, soldering, welding and brazing, ultrasonic cleaning, and so forth. The DSCS-II specification has a similar section between pages 49 and 52. INTELSAT apparently believes that such detailed specifications are unnecessary.

General Contract Style

The basic INTELSAT contract has typically been confined to stating the equipment and services to be furnished, delivery schedule, payment plan, satellite performance incentives, access to work in progress, inspections and acceptance conditions, indemnification for taxes, termination, change provisions, key personnel, damages, and options. Exhibits attached to the contract contain the satellite specifications, the statement of work (which includes documentation requirements), the quality assurance plan, detailed test plan, radiation environment, INTELSAT's procurement regulations, and the milestone-oriented partial payment plan. The earlier contracts were entirely self-contained and no external documents were referenced. The INTELSAT VI contract does include references to a few external standards (discussed below).

Air Force contracts are written in accordance with the Defense Acquisition Regulation (DAR), which is approved by Congress. The DAR requires that several of its own clauses be incorporated into each contract. For example, the DSCS-II follow-on procurement contract contains 82 DAR clauses.[4] These clauses include contract work hours and overtime compensation, equal opportunity, gratuities, convict labor, subcontracting plan for small business and small disadvantaged business concerns, utilization of labor surplus, cost accounting standards, use of domestic speciality metals, and affirmative action plans for handicapped workers, disabled veterans, and veterans of the Vietnam war. Some of these clauses require potential contractors to incur additional direct expenses; others require delays which are costly. Because the costs of some requirements are buried in overhead accounts, the cost impact of these clauses is not identifiable, and they cannot be subtracted when comparing costs with INTELSAT contracts.

[4]This contract actually incorporated clauses from the Armed Services Procurement Regulation (ASPR). Since the DAR wholly succeeded the ASPR, and the clauses to be discussed here are similar in intent and impact on the contract, DAR will be used to refer to both documents.

These DAR clauses appear in a section of the contract called General Provisions. This section also contains clauses tailored to the contract, such as provisions for contract changes, release of news information, subcontract management plan, patent provisions, and so forth. These tailored General Provisions are similar to the basic INTELSAT contract.

Progress Payments

Air Force and INTELSAT contracts both list the items to be delivered and contain plans for payments to the contractor as work is completed. The INTELSAT payment plan is much more detailed than the DSCS plans and is *event* (accomplishment) oriented. Several hundred discrete events are identified in the contract, and a payment amount is specified for the completion of each event. The sum of all such progress payments equals the total contract price. The Air Force payment plan has two elements. As the contractor's work progresses, he submits vouchers for costs incurred. The Air Force pays 80 percent of the costs as they are incurred, and then pays the remainder of the price (including profit) for an end item or event when it is delivered, accomplished, and/or approved.

Theoretically, since the INTELSAT plan contains a greater number of accomplishment-oriented milestones, INTELSAT should be able to identify problem areas sooner than the Air Force, and to signal their concern to the contractor by withholding payments. However, in the projects we have examined the two plans resulted in roughly similar overall payment schedules and there is no evidence that one approach produces better program outcomes than the other.

External References

Like INTELSAT contracts, Air Force contracts contain a statement of work. However, for Air Force contracts, the statement of work lists applicable documents (Military Standards, Military Specifications, Interface Control Documents) with which the contractor must comply in performing the work. The satellite performance specifications, normally prepared by the contractor and approved by the Air Force, are added to this list of compliance documents. The specifications refer in turn to Military Standards and Military Specifications. Subsystem performance specifications, system test plans and procedures, configuration management plans, and quality control plans may also be added to this list as they are approved. If these last items are not on the compliance list, they generally are placed on a second list of documents called the reference list. A contractor need not necessarily comply with documents on the reference list. Table 4 shows the number and type of external documents incorporated into the DSCS specifications. This concept of lists of external compliance and reference documents had no equivalent in INTELSAT contracts until the ISAT-VI, discussed below.

The documentation to be delivered by the contractor to the Air Force is specified on a form called a Contract Data Requirements List (CDRL).[5] The CDRL identifies what must be documented, the contents and format of the document, when it must be delivered, and if Air Force approval is required. The CDRL generally references a Data Item Description (DID) to identify the contents and format. There are several thousand DIDs and a complete listing would take over a foot of shelf space. This is unlike INTELSAT where all data items are fully described within the statement of work.

[5]A CRDL is included in the ISAT-VI contract, but there it is appended to the Work Statement largely as a convenience in identifying all required documents in one place, rather than as a method of contractually specifying deliverable data.

Table 4

DOCUMENTS INCORPORATED IN DSCS SPECIFICATIONS

Document Type	Number of Documents Incorporated by Program	
	DSCS-II	DSCS-III
Military Specifications	5	13
Federal Specifications	0	1
Space Division Specifications	0	1
Federal Standards	0	1
Military Standards	4	15
Space Division Standards	0	1
Marshall Space Flight Center Standards	0	1
Military Design Handbooks	1	4
National Security Agency Standards	0	7
NASA documents	0	3
NSA documents	2	2
NSS documents	0	1
Aerospace Corp. documents	1	1
NAS Standards	1	0
Range Safety Manuals	1	0
Booster interface documents	3	5
Contractor standards, specifications, drawings, and other documents	9	54
Institute for Printed Circuits documents	0	3
Total	27	113

Some of these differences between INTELSAT and Air Force contracts are a result of differences in organization staffs. INTELSAT can draw on a fairly large and stable staff of highly experienced personnel and relies on them to write a contract that defines exactly what is needed. Because they must create each sentence of each contract document, they have a great incentive to include only those requirements which are truly needed. On the other hand, in the Air Force—because of its tendency to rotate senior and middle-level officers—less experienced personnel write the contract. These people start with a "laundry list" of external documents that reflect the institutional experience of the entire Department of Defense. They are then expected to determine what is *not* needed for the specific contract and tailor the Military Specifications and Standards, DIDs, etc. to remove it. The military has at least two incentives to keep this list as full as possible. First, removing any document could expose or make vulnerable the Air Force Contracting and Management staff. It is conservative to leave everything as is. And second, to remove unneeded items requires additional paperwork and other forms of documentation.

Expecting relatively junior, and often overworked, officers in program offices to tailor out requirements against the advice of senior staff personnel is naive. Since the staff has no cost accountability, they tend to keep most requirements in the contract. After all, the staff can only be blamed if a requirement was deleted that later proves to have been needed.

These differences lead to Air Force contracts that do not stand alone, are generally more difficult to read, and require a multi-discipline staff to fully understand them. INTELSAT contracts stand alone and are fairly easy to read.

As the INTELSAT organization matures, however, its contract practices have been evolving and their contracts are beginning to acquire added levels of detail and complexity. For INTELSAT programs up to and including the ISAT-IVA, the entire contract, including all exhibits, was never much more than an inch in thickness and could easily be contained in a standard notebook. The ISAT-V basic contract was about three inches thick, with half of that devoted to the test plan. The ISAT-VI contract, the most voluminous INTELSAT contract yet, requires nearly five inches of shelf space to contain the entire contract with all exhibits. The quality assurance section of the ISAT-VI contract is nearly 10 times as long as the comparable sections of the ISAT-IV and ISAT-V contracts. Furthermore, for the first time the ISAT-VI contract includes, by reference in the product assurance plan (Exhibit C), eight Military Specifications, five handbooks published by the government and professional societies, and numerous contractor specifications. Many of those specifications apply to design and fabrication, rather than to end-item performance. Furthermore, ISAT-VI was the first INTELSAT program where the contractor reporting requirements became so extensive as to justify a "Contract Data Requirements List" (attachment 4 to the Statement of Work). This list specifies 50 different kinds of reports, many of which recur throughout the program (a separate issue of one report is required for each design review, for example). Thus some of the differences between INTELSAT and the Air Force practices seem to be diminishing.

PROJECT OFFICE ACTIVITIES

One theme that recurs in criticism of weapon system acquisition management is that the military tends to "micro manage" such projects, thereby inhibiting the contractor from efficiently performing his duties. The DSCS programs were managed through a System Project Office (SPO) that appears to have been organized and operated in general conformance with usual Air Force practices. INTELSAT also maintained an SPO to monitor the contractor's performance and perform whatever other management functions were deemed necessary and appropriate. This study therefore offered an opportunity to compare the organization and duties of the INTELSAT and Air Force project offices and to determine if the commercial organization, free from regulations and traditions of the military acquisition organizations, chose to manage their projects in a significantly different way.

The results of this comparison, outlined below, are striking more for their similarities than for their differences. Despite the fact that fixed-price contracts were used, and that those contracts included rather extensive and detailed descriptions of the performance and other salient features of the spacecraft, and that all contracts included extensive incentive clauses, neither INTELSAT nor the Air Force treated their procurements as "turnkey" operations. Instead, both organizations carefully monitored the contractors' activities, and ensured through contractual language that SPO personnel would have unrestricted access to work in progress and would have power to approve or disapprove a wide variety of design decisions. In the pro-

grams we examined, INTELSAT observed its contractors' activities at least as intently as did the Air Force.[6]

In almost all important aspects, the Air Force and the INTELSAT SPOs functioned in similar ways. One difference was in their physical location. The Air Force SPO was always located at the Air Force Space Division in Los Angeles, even though the DSCS-III satellite contractor was located in Pennsylvania, whereas INTELSAT always located their SPO adjacent to the contractors' plant. Each scheme has advantages and disadvantages, and the analysis of the projects in this study yielded little evidence that one scheme is better than the other.

One measure of SPO activities lies in staff size. Both organizations maintained a total project staff size of 70 to 80 people throughout the development and early production phases of the various programs. In all cases, those personnel were partly client staff (i.e., Air Force and INTELSAT personnel) and partly contract personnel (Aerospace Corporation supporting the DSCS project office, and COMSAT Laboratories and other contract personnel supporting the INTELSAT SPOs).

Portions of both SPO staffs were highly qualified technical experts, with skills covering most of the major disciplines involved in communications satellite development. Those people monitored all major aspects of the satellite development, including participation in every design review conference, and review of test plans and monitoring of actual test results. They directly advised the head of the project office, who maintained major oversight control over the design and manufacturing process through approval authority over all design reviews and progress payments.

The most important difference between INTELSAT and the Air Force was that the INTELSAT SPO consisted mostly of technical experts, and focused largely on technical issues, whereas in the Air Force SPO roughly half of the activity was focused on cost management and budgeting. That difference was probably dictated in part by different contract forms—the Air Force had a cost-sharing clause if contractor costs were above a target value—and in part because the Air Force SPO has many layers of management above it—the DSCS satellite program constitutes only a small part of the overall Air Force program.

DISCUSSION

The comparison of Air Force and INTELSAT management structure and acquisition practices revealed more similarities than differences. Both organizations initiated their acquisition programs by awarding fixed-price contracts to the winners of concept/design competitions. Both organizations then proceeded to change and amend the contract as the program matured. All such follow-on contracts were negotiated with the sole source producer. The two organizations also specified their spacecraft performance and test requirements in similar fashion, and staffed and operated their SPOs in a similar manner.

On the other hand, we did observe some significant differences between Air Force and INTELSAT activities. INTELSAT uses firm-fixed-price contracts and bases its payments to the supplier solely on demonstrated progress in design, production, and delivery. The Air Force uses fixed-price-incentive contracts, pays a portion of design and production costs as they are incurred, and pays the remainder (plus a negotiated profit percentage) when end items

[6]In this respect INTELSAT differs substantially from the typical commercial purchaser of spacecraft. The typical purchaser would be a firm with more expertise in applications than design or production and would be interested more in proven technology than state-of-the-art improvements.

are delivered. The Air Force contracts are more detailed, containing many references to external documents, process specifications, and data requirements. The early INTELSAT contracts were self-contained, but more recent ones are beginning to evolve toward the Air Force example.

Finally, we observed a major difference in personnel. INTELSAT draws on a fairly stable group of experienced professionals, expert in the ways of communication satellites. The Air Force policy of rotating its career personnel results in less across-the-board technical expertise. Partly as a result of that, the Air Force SPO concentrates more of its efforts on financial and configuration management than does INTELSAT. INTELSAT stations the core of its support group near the contractor's plant and observes his technical progress, or lack thereof, first-hand and continuously.

IV. COMPARISON OF ACQUISITION PRACTICES: INCENTIVES

Spacecraft acquisition contracts written by the Air Force and INTELSAT all call for the completion of detailed tasks and the delivery of specific end items on an explicit schedule. They all provide for termination and payment of damages if the specifications are not fulfilled.

Both organizations write incentives into their contracts. These incentives take many forms. Some make it profitable to the contractor to complete tasks or deliver items ahead of the nominal schedule. Others pay extra if the spacecraft exceed the design specifications or if they perform longer in orbit than required by the contract. Still others may penalize the contractor if he exceeds the schedule, increases the price, or produces a less-than-satisfactory end item.

Incentives are a contractual method of dealing with uncertainty. If there are no risks associated with a project, incentives are not needed—the buyer and seller execute a simple contract and one pays for the item when the other delivers it. Incentives are also not needed if the two parties agree beforehand to renegotiate the contract, or to go directly to arbitration or litigation, if anything unexpected happens to affect the performance of either party.

Both the Air Force and INTELSAT, however, incorporate explicit incentives into their spacecraft acquisition contracts, using these clauses to express joint agreement with their contractors on actions to be taken when the acquisition program encounters major uncertainties. If, for example, during design and testing the contractor finds that it is going to be technically feasible to produce a better than specified product for close to the specified price, a well-written performance incentive will encourage him to do so. On the other hand, if he finds he cannot fully comply with the contract specifications, the incentive provides a graded schedule of penalty payments as an alternative to total default. Similarly, schedule incentives can reward the contractor who finds he can deliver an end item ahead of schedule, or they can help avoid default if delivery cannot be made precisely on time.

Cost incentives, if any, will come into play whenever actual costs begin to diverge from expected costs. If costs are running at a greater than expected rate, a cost incentive can encourage the contractor to continue production rather than defaulting, while at the same time encouraging him to economize as much as possible since each extra dollar that he incurs reduces his profits. If, on the other hand, actual costs are less than expected, the cost incentive generally will still encourage the contractor to economize since both parties will typically share the underrun.

The one major problem with contractual incentive clauses is that they bind both parties to an agreement made at the time the contract is signed or the incentive clause is amended. Renegotiations, by contrast, allow either or both parties to update their preferences after the major uncertainties have become known and perhaps resolved. However, apparently both the Air Force and INTELSAT believe it is worthwhile to place their preferences on the record when the contract is signed, since, even when incentives are incorporated into a contract, renegotiation and contract amendments can later be made whenever both parties find it is in their mutual, as well as individual, interest.

In summary, incentives serve several functions when acquisition programs contain large elements of uncertainty: (1) they encourage continued production by providing contractual alternatives to termination or cancellation; (2) they provide explicit penalties for performance and schedule shortfalls; (3) within that context they are a contractual means of sharing risks

between the buyer and the seller; and (4) they are a convenient and apparently effective means of encouraging and rewarding a contractor for better-than-expected results (if he finds such results can be achieved cost efficiently).

A comparison of Air Force and INTELSAT contracts and prices indicates that there have been noticeable differences in their use of contract incentives. The general characteristics of their schedule, performance, cost, and award-fee incentives are discussed below. There is additional detail on INTELSAT and DSCS incentives in Apps. A and B, respectively.

SCHEDULE INCENTIVES

INTELSAT contracts all have some type of incentive for on-schedule delivery of spacecraft. They usually take the form of penalties for late delivery, but two contracts also call for bonuses to be paid if spacecraft are delivered ahead of schedule. DSCS-II contracts contain similar provisions. We shall discuss these in turn.

INTELSAT Schedule Incentives

INTELSAT typically assesses schedule penalties against its spacecraft suppliers if the first or second satellites are delivered later than either the date specified in the original contract or some amended or negotiated later date. There is always a provision for "excusable" delays and always a maximum period or dollar amount limiting the penalties. If delivery is delayed beyond that period for some inexcusable reason, the contract can usually be terminated.

We put these schedule incentives in perspective in Table 5, which expresses the maximum possible bonuses and penalties that could be earned by the various spacecraft as a percent of the spacecraft delivery price.[1] The delivery price is computed as the full contract price before *any* incentives are considered. In this and several following tables, F-1 refers to the first flight spacecraft produced under the contract, F-1/6 to the first six, etc.[2]

The penalties attached to late delivery of the first ISAT-IV were substantially greater than the others. They could amount to half of the basic price of the ISAT-IV spacecraft, whereas most other spacecraft penalties were limited to 10 percent or less. The more recent tendency is to set these penalties set at 4 or 5 percent of the spacecraft price.

Discussions with INTELSAT officials indicate that perhaps half of the schedule penalties were actually realized. They reported that the ISAT-III program was at least eight weeks late and full delivery penalties were assessed on each satellite. The ISAT-IVs were delivered in compliance with an amended schedule, which was some 10 to 11 weeks later than originally scheduled due to other contract changes, but no penalties were paid. ISAT-IVA also slipped slightly because of changes and no penalties were assessed. On the other hand, there were long delays in ISAT-V deliveries and maximum schedule penalties were assessed.

[1]For Table 5 we estimated separate prices for the spacecraft associated with separate buys. In general, we associated only items specifically linked to the add-on spacecraft with the second (or third) buy; all remaining items (including development) were associated with the first (basic) buy. This procedure was clearcut for ISAT-II and -III but more complicated for ISAT-IV, -IVA, and -V. Consequently, the entries in the table should be viewed only as rough estimates.

[2]In the individual contracts many designations are used to identify individual spacecraft. For example, DFS-2 may refer to the second demonstration flight spacecraft of a series and B-3 may refer to the third spacecraft in the second buy or contract. For simplicity we will only use the designation "F" in this Report.

Table 5

INTELSAT SCHEDULE INCENTIVES AS PERCENT OF SPACECRAFT DELIVERY PRICE[a]

	Maximum Incentive as Percent of Price[c]	
Item[b]	Bonus	Penalty
ISAT-I		
ISAT-II		
F-1 and 2		6
F-5	7	7
ISAT-III		
F-1/6		1
F-7		13
F-8		7
ISAT-IV		
F-1		50
F-2		7
ISAT-IVA		
F-1		9
F-2		1
F-4		10
F-5		1
ISAT V/VA		
F-1/7	1	4
F-8		5
F-9		5
F-10/12		5
F-13/16		5
ISAT VI		
F-1/5		4

SOURCE: INTELSAT contracts and amendments.

[a]Delivery price is the full contract price before any incentives are added or deducted.

[b]Items include all spacecraft to which schedule incentives were attached. F-1 refers to the first flight spacecraft of the series, F-2 to the second, etc.

[c]Prices were estimated as amounts expended for individual spacecraft and do not include launch costs or performance incentives. See footnote 1 on previous page for additional details.

DSCS Schedule Incentives

Schedule incentives were applied to both of the DSCS-II contracts. The initial contract contained penalties for late delivery of (1) certain subsystem specifications, (2) the satellite qualification procedure, and (3) the two flight spacecraft. The follow-on contract offered bonuses for early delivery of the first two spacecraft. We found no schedule incentives in the DSCS-III contracts.

Table 6 expresses the DSCS incentives as percentages of the spacecraft delivery prices.[3] Note that these penalties are much smaller than those associated with the INTELSAT contracts, and recall that *no* schedule incentives are associated with any of the DSCS-III contracts.

ON-ORBIT PERFORMANCE INCENTIVES

INTELSAT contracts all contain incentives for satisfactory on-orbit performance. The incentives are usually positive, in the form of bonuses for successful performance, although some contracts involve paybacks if subsequent performance is unsatisfactory.

DSCS-II and -III contracts also contain provisions for on-orbit performance incentives. The early DSCS-II and DSCS-III contracts provided for both bonuses and penalties; the more recent contracts concentrate on penalties.

INTELSAT Performance Incentives

All INTELSAT spacecraft contracts have provisions for on-orbit performance incentives. The incentives are designed to encourage development and manufacturing practices that increase the probability of the satellites operating successfully throughout their design life. The incentives also encourage the manufacturer's cooperation and support for the initial on-

Table 6

DSCS-II SCHEDULE INCENTIVES AS PERCENT OF SPACECRAFT DELIVERY PRICE

	Maximum Incentive as Percent of Price	
Item	Bonus	Penalty
Specifications and procedures		1.9
Delivery of F-1 and F-2		4.1
Delivery of F-7 and F-8	0.4	

SOURCE: Table B.6.

[3]In constructing Table 6 we assumed that the original portion of the initial contract covered all development activities and represented the "price" of the specifications and procedures named in the table; we estimated the unit price of F-1 and F-2 by spreading the total contract growth of that contract evenly over the six spacecraft specified in the major amendment; and we estimated the price of F-7 and F-8 by spreading the current amount of the replenishment contract evenly over the eight spacecraft procured thereunder.

orbit checkout and for malfunction analysis and corrective action identification during the life of the satellite.

Performance incentives are typically paid:

- If the spacecraft is injected into the correct orbit and operates successfully for an initial period
- If it continues to operate satisfactorily;
- If a spacecraft is accepted by INTELSAT but not launched within 90 days
- if the booster fails to place the spacecraft into the proper geostationary transfer orbit and attitude or if the spacecraft is damaged by its launch vehicle.

Performance incentive payments may be positive (giving the contractor bonus money for each period that the satellite operates successfully up to its design lifetime) or negative (the contractor pays the customer a penalty for each period the satellite fails to successfully operate) or a combination of both. Several of the more important characteristics of the incentive provisions for the INTELSAT satellites are shown in Table 7.

The ability of incentive payments to influence the total price paid for different satellites is shown in Table 8. The table shows the characteristics of the performance incentives paid on the first spacecraft of each series. The payments are all expressed as a percent of the maximum price that could be paid—the maximum price includes the delivery price and all performance incentives that would be earned if the spacecraft operated successfully for its entire

Table 7

PERFORMANCE INCENTIVE SCHEDULES FOR INTELSAT SPACECRAFT

	Length of Performance Period		
System	Initial (Days)	Total (Years)	Payment Schedule
ISAT-II	30	4	Payments made monthly
ISAT-III	30	6	Payments made monthly
ISAT-IV F-1/4	30	7	Payments made monthly
F-5/8	30	7	Full payment after 30 days; refunds for later failure
ISAT-IVA	30	7	Full payment after 30 days; refunds for later failure
ISAT-V/VA	90	7	Payments monthly after 1st qtr
ISAT-VI	90	10	Penalty assessed at end of year 1 if spacecraft fails initially or during year 1 Payment for years 1-5 made at end of year 1; refunds for failure during years 2-5; payments made monthly during years 6-10

SOURCE: INTELSAT contracts and amendments.

Table 8

PERCENT OF MAXIMUM PRICE PAID UNDER ALTERNATIVE PERFORMANCE SCENARIOS

		Performance Scenario			
Program	Design Life (yr)	Design Life (%)	Half-Life (%)	Initial Failure (%)	Launch Failure (%)
ISAT-II	4	100	79	57	68
ISAT-III	6	100	85	66	82
ISAT-IV	7	100	95	74	91
ISAT-IVA	7	100	96	83	100
ISAT-V/VA	7	100	88	75	94
ISAT-VI	10	100	88	72	92

SOURCE: Analysis of INTELSAT contracts.
NOTE: Entries apply to first satellite in each series.

design lifetime. The table shows the percent of maximum price which is paid if the satellite operates successfully: (1) throughout its full design life; (2) throughout the first half of that design life and then fails; or (3) does not ever operate satisfactorily. It also shows the percent of maximum price a supplier can collect for a spacecraft in the event a booster failure that is not his fault eliminates its chances of earning performance payments.

Table 8 highlights several aspects of the performance incentives. First, the incentives represent a significant portion of total price. In the least case, for ISAT-IVA, the on-orbit incentive can make a difference of 17 percent in the full price received by the spacecraft supplier. Second, the contribution of incentive payment to maximum price has changed over time. The price of an ISAT-II that failed immediately was 43 percent less than the full price of one that operated satisfactorily throughout its full four-year design life. This represents the most influence or leverage of performance on price among the contracts. The difference between minimum price and maximum price (see the "initial failure" column) fell for ISAT-III and again for ISAT-IV and -IVA, respectively. But then the trend reversed, and the percentage increased for ISAT-V and for ISAT-VI.

Since incentives are a way of agreeing on program objectives, it seems logical to assume that the trends in incentive payments shown in Table 8 are related to the ways that INTELSAT and its contractors viewed the major risks in the different programs. It appears they believed the risk of unsuccessful performance was decreasing over time, at least through the ISAT-I, -II, -IV, and -IVA series produced by Hughes. That trend culminated in ISAT-IVA, which was a modest refinement and extension of the ISAT-IV design and may have represented a minimum level of technical risk for these systems.

This interpretation seems consistent with other another trend shown in Table 8. The booster failure compensation steadily increases from ISAT-II through ISAT-IVA, presumably reflecting the notion that the probability of extensive service life (and corresponding incentive payments) is increasing from one program to the next. However, both of these trends reverse after ISAT-IVA, suggesting that the most recent programs may involve more challenging design objectives and carry higher risks of failure.

One further aspect of the performance payments is worth examining. INTELSAT officials contend that under most of their contracts the spacecraft supplier loses money if his spacecraft do not perform well on-orbit. Since we saw in Table 8 that spacecraft prices could have varied historically by as much as 34 percent, and more recently by 25 to 28 percent depending on performance, the INTELSAT beliefs are probably valid. It would be unrealistic for a contractor to assume he could achieve more than that level of profit on these contracts.

DSCS Performance Incentives

Both the DSCS-II and DSCS-III contracts specify on-orbit performance incentives for flight spacecraft, but the details differ significantly.[4] The incentives are similar to the ones found in INTELSAT contracts in that they are contingent on successful operation of the communication mission of the satellites and they are designed to encourage development and manufacturing practices that increase the probability that the satellites will operate successfully through their entire design life. Several of the more important characteristics of the incentive provisions for DSCS satellites are shown in Table 9.

The ability of incentive payments to influence the total price paid for the different DSCS satellites is shown in Table 10, which again shows the characteristics of the performance incentives paid on the first spacecraft of each series. The payments are all expressed as a percent of the maximum price that could be paid (again including both delivery price and all earned performance incentives) if the spacecraft operates successfully for its entire designed life.

Table 10 shows that on-orbit incentives have helped to determine the full price the DSCS supplier receives for his satellites, but that they are less important now than previously. This is in sharp contrast with the INTELSAT situation, where the importance of incentives has remained relatively constant at about 25 to 30 percent of the maximum price.

The tendency of DSCS contracts to deemphasize performance incentives culminates in the DSCS-III production contract, which allows the maximum price to be paid if the satellite

Table 9

PERFORMANCE INCENTIVE SCHEDULES FOR DSCS SPACECRAFT

System	Length of Performance Period: Initial	Length of Performance Period: Total	Payment Schedule
DSCS-II			
F-1/4	60 days	5 years	Payments computed bimonthly[a]
F-7/16	60 days	5 years	Payments computed bimonthly[a]
DSCS-III			
F-1/2	60 days	10 years	Payments computed bimonthly[a]
F-3	60 days	7 years	Penalties only
F-4/7	1 year	4 years	Penalties only

SOURCE: DSCS contracts and amendments.

[a]Payments apparently are made semi-annually.

[4]Supplementary material on DSCS on-orbit incentives can be found in App. B.

Table 10

PERCENT OF MAXIMUM DSCS PRICE PAID UNDER ALTERNATIVE PERFORMANCE SCENARIOS

Program	Design Life (yr)	Performance Scenario: Design Life (%)	Half Life (%)	Initial Failure (%)	Launch Failure (%)
DSCS-II					
Initial	5	100	85	59	81
Replenishment	5	100	93	83	(a)
DSCS-III					
Development	10	100	94	83	91
Refurbishment	7	100	99	97	100
Production	10	100	100	93	100

SOURCE: Analysis of DSCS contracts.
NOTE: Entries apply to first satellite in each series.

[a]On-orbit incentives are added to future satellites.

performs satisfactorily for the first four years of its 10-year design life, or in the event of booster failure. If the satellite fails to perform at all, the supplier still receives 93 percent of the maximum amount.

One further analysis of the DSCS data is interesting. The Air Force, unlike INTELSAT and other commercial buyers, attempts to establish and monitor the cost performance of its suppliers. All of the DSCS contracts appear to be written so that the target price corresponds to the supplier's target cost, which the Air Force presumably accepts as a reasonable estimate of the supplier's probable total costs, plus a profit margin of 11 percent. This information allows us to examine the effect of spacecraft performance on the supplier's "profit" from the satellite programs.

Table 11 shows the findings of this procedure. Its entries represent the percentage by which the total price received by the supplier in each case exceeded the target cost. All but one of the entries in this table are positive, meaning that in almost all combinations of on-orbit performance outcomes the DSCS contracts specify prices that are above target costs. That is, except for the first contract, the payments to the supplier exceeded his target cost, even if the satellites failed to operate at all. The early contracts called for quite substantial "profits" if the satellites performed up to their design specifications. If the satellites operated for half their design life, the margins are still above the 11 percent usually thought of as the "normal" or target level, but not much above since portions of these payments will probably not be valued as highly by the contractor looking for an early return on his investment.[5]

[5]This entire discussion relates only to the profit margins written into the contract. If actual costs turn out to exceed target costs, the actual profits will, of course, be reduced, even if the spacecraft perform perfectly. If the Air Force and the contractor believe, at the time of contract negotiations, that the negotiated target cost level will be exceeded, they are, in effect, anticipating smaller profit rates than the ones they specify in the contracts.

Table 11

DSCS TARGET PROFIT UNDER ALTERNATIVE PERFORMANCE SCENARIOS

Program	Design Life (yr)	Target Profit Rate[a] Under Alternative Scenarios: Design Life (%)	Half Life (%)	Initial Failure (%)	Launch Failure (%)
DSCS-II					
Initial	5	36	16	-19	11
Replenishment	5	24	15	3	(b)
DSCS-III					
Development	10	28	20	5	17
Replenishment	7	12	11	9	12
Production	10	11	11	3	11

SOURCE: Analysis of DSCS contracts.
NOTE: Entries include payments for all satellites in each series.

[a]Percent by which total price exceeds target cost.

[b]On-orbit incentives are added to future satellites.

The definite trend in these contracts is to reduce profit margins, although the DSCS-III development contract deviates slightly from that trend. The latest contract allows only for the target 11 percent margin even if the satellites perform perfectly. Note finally that these contracts, again with the exception of the DSCS-III development contract, specify that the supplier will receive only his target rate of return in the event of booster failure.

Summary of Performance Incentives

Figure 1 compares INTELSAT and DSCS on-orbit performance incentives and their part in determining the full price paid for communication satellites.[6]

The Air Force has always preferred to assess penalties for early on-orbit failures rather than to simply withhold payments, and the most recent INTELSAT contract also takes this approach. Whatever form the performance incentives take, INTELSAT attempts to target a particular total price (delivery plus incentives) based on anticipated satisfactory performance. Positive incentives thus imply that the contractor receives a large portion of his payment late in the program; negative incentives imply that he receives a larger portion of the payment earlier. Discussions with Air Force personnel indicate that DSCS contractors also wish to receive as much as possible of their payment "up front."

[6]Note that Fig. 1 relates total program incentives to total program price, whereas the previous discussion often gave estimates based only on the first satellite in each program.

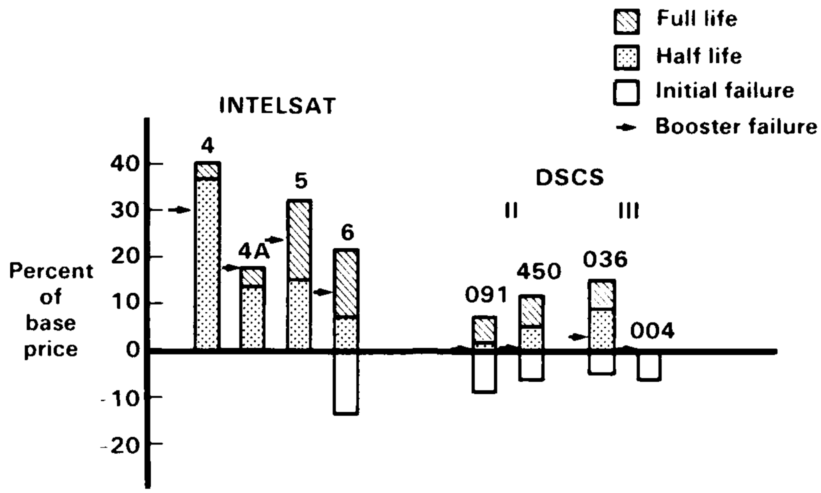

Fig. 1—On-orbit performance incentives

INTELSAT continues to stress performance incentives, keeping them between 20 and 30 percent of the satellite delivery price. In the more recent DSCS contracts, on the other hand, performance incentives are less important than they were earlier.

On-orbit incentives are also a form of product warranty, an acquisition tactic that the Congress has been urging the Department of Defense to use more widely. In fact, on-orbit performance incentives might be the only form of warranty that is possible on a nonreturnable item like spacecraft. A negative incentive (where the supplier has to pay a penalty for a shortfall in performance) is the most direct analog to the traditional warranty concept, and such negative incentives have been included in every Air Force DSCS contract. Positive performance incentives are also warranties. Withholding payment in the event of a performance problem is an equally severe form of recompense.

COST INCENTIVES

Cost incentives are usually expressed as a sharing formula by which the supplier and the customer participate in cost underruns and overruns. They are commonly found in Air Force contracts. We find only one instance of INTELSAT using a cost incentive and are informed that it was adopted to reconcile differing interpretations of a signed contract.

The INTELSAT Cost Incentive

Amendment 8 to the ISAT-IV contract provided for the purchase of four additional spacecraft at a total price of $20.9 million, and allowed for the possibility of an additional $15.1 million in on-orbit incentives. It also required the contractor to keep a separate set of books documenting the costs associated with these spacecraft and gave INTELSAT the right to audit those books. The amendment then specified that if Hughes' costs turned out to be less than

$30 million, "the total prices payable hereunder . . . shall be reduced in an amount equal to 70 percent of the difference between the Contractor's costs for completion . . . and $30 million."

Although that was the only cost incentive we found in the INTELSAT contracts, we did find another interesting price redetermination clause, also with Hughes. This clause[7] was associated with the original buy of ISAT-IVAs. INTELSAT negotiated directly with Hughes for a price reduction of $0.5 million per spacecraft purchased by INTELSAT if Hughes should enter into any contract to sell similar spacecraft to another buyer within 120 days of the effective date of the INTELSAT contract. Amendment 2 to the ISAT-IVA contract indicates that Hughes did sell additional spacecraft to others and consequently INTELSAT paid the lower price.

The DSCS Cost Incentives

The DSCS contracts all contain cost incentives, as summarized in Table 12. The first contract is typical. The first DSCS-II contract was signed for development effort, data, and reports, and some long-lead-time items. Target cost was $33.9 million and target profit was $3.8 million,or just over 11 percent of the target cost. These items summed to a target price of $37.7 million. Ceiling price was $40.7 million, or exactly 8 percent more than the target price. The incentive price revision clause of the contract provided that the contractor and the Air Force share equally in cost overruns (up to the ceiling price, at which point the contractor would bear all subsequent costs) and in cost underruns (so long as the performance of the satellites was at least "par").[8]

The cost incentives in the following DSCS contracts differed only in a few details—the government participates more fully in underruns and overruns now, and the target profit rate has skipped around a little, although typically remaining close to 11 percent. Generally, the Air Force seems consistent in its application of cost incentives.

AWARD FEES

The DSCS-III refurbishment and production contracts contain provisions for an "award fee" in addition to penalties for less-than-satisfactory performance by an on-orbit spacecraft.[9] The DSCS SPO believes that an award fee, which can be earned as the contractor is constructing and testing the spacecraft, has the potential for more leverage on contractors than do on-orbit bonuses, which can only be earned after the design is fixed and production is under way or even completed.

> Award Fee is additive to the usual profit negotiated for a fixed price incentive-firm (FPIF) contract. Therefore, no Award Fee shall be awarded when performance is merely satisfactory and meets contract requirements. To merit Award Fee, the contractor must exceed normally expected performance for those areas to which the fee applies. Consequently, contractor's efforts rated below the Award Fee standard of "Good" will render the contractor ineligible to receive any Award Fee for the pertinent performance evaluation criteria.[10]

[7]Article XIV of the ISAT-IVA contract.

[8]Details on DSCS prices and expected costs are given in the appendixes, especially Tables C.14 through C.18.

[9]Supplementary material on DSCS award fees can be found in App. B.

[10]Attachment 10 to contract F04701-81-C-0004, *Award Fee Evaluation Plan, Defense Satellite Communications System III, Phase Three Space Segment*, November 1, 1982, p. 4.

Table 12

CHARACTERISTICS OF DSCS COST INCENTIVES

Item	Target Profit Rate[a]	Cost Sharing Rate[b]	Cost Sharing Limit[c]
DSCS-II			
Initial contract			
Original version	11	50/50	8
Replenishment contract			
Original version	11	80/20	13
Current version	11	80/20	10
DSCS-III			
Development contract			
Original version	4	80/20	19
Current version			
FPI items	6	80/20	16
FFP items	na	0/100	na
Refurbishment contract			
Current version	11	80/20	8
Production contract			
Current version			
FPI items	11	70/30	8
CPFF item	8	100/0	na

SOURCE: DSCS contracts.

[a]Target profit rate is target profit expressed as a percent of target cost.

[b]Cost sharing rate shows the percent of cost overruns and underruns allocated to the Air Force (numerator) and the contractor (denominator).

[c]Cost sharing limit expresses the difference between ceiling price and target price as a percent of the latter.

The award fee section of the production contract goes on to state that it "deals with areas under the control of management which are mostly susceptible to subjective evaluation" and "therefore, precise definition of all the factors possible for consideration is impossible." Nine areas, however, were listed as pertinent to the award fee evaluation:

Program/subcontractor/vendor management
Cost management
System test and evaluation
Product assurance/system effectiveness
Systems engineering
Configuration management
Production management
Launch vehicle integration and launch support
TWTA subcontract management

The contractor can potentially earn $1.85 million under this provision of the refurbishment contract and $15 million under the production contract. Thus, for these contracts, the award fees are nearly as important as the on-orbit incentives.

DISCUSSION

The INTELSAT and DSCS incentives are summarized in Table 13, which expresses the maximum incentives—both bonuses and penalties—as a percent of the delivery price of the spacecraft.[11] The final column of Table 14 aggregates the individual incentives to indicate the maximum increases and decreases to the delivery price that the combined effects of the incentives could produce.

It is clear that incentives have been and will continue to be important in determining the full price paid for communication satellites. INTELSAT consistently provides for schedule and performance incentives, and consistently attaches greater significance to the performance incentives. The Air Force, on the other hand, concentrates on performance and cost incen-

Table 13

POTENTIAL EFFECTS OF INCENTIVES ON SPACECRAFT PRICE

	Maximum Incentive Effects				
System	Schedule	On-orbit Performance	Cost[a]	Award	Totals
ISAT-I		+46			+46
ISAT-II	-3 +1	+41			-3 +42
ISAT-III	-3	+18			-3 +18
ISAT-IV	-10	+40			-10 +40
ISAT-IVA	-3	+19			-3 +19
ISAT-V	-4 +1	+32			-4 +33
ISAT-VI	-4	-13 +21			-17 +21
DSCS-II					
Initial	-3	-9 + 7	+4		-12 +11
Replenishment	+1	-6 +11	+8		-6 +19
DSCS-III					
Development		-6 +17	+13		-6 +30
Refurbishment		-10	+6	+3	-10 +9
Production		-6	+6	+4	-6 +10

SOURCE: Tables A.4, A.11, B.13, C.1, and C.20, and on material from INTELSAT and DSCS contracts and amendments.

NOTE: Incentives include maximum earnings (and penalties) for all spacecraft in each series and are not discounted or escalated.

[a]Cost incentives attached to ISAT-IV and all DSCS contracts may reduce prices by indefinite, but significant, amounts.

[11]Note that the percentages in Table 13 differ from those found in several other tables because the percentages here are based on the entire program rather than on individual spacecraft.

tives, attaching nearly equal weight to each. Compared with INTELSAT, the Air Force has tended to put less emphasis on incentives, and that Air Force emphasis appears to be decreasing further. Only time will tell if award fee procedures become an important aspect of satellite contracts.

Table 14

SYSTEMS COMPARED

System	Manufacturer	Program Start	Unit Price[a]	Stabilization Method	Weight (lb)
ISAT-IV/IVA	Hughes	1968	40	Spin	1600
DSCS-II	TRW	1969	35	Spin	1300
ISAT-V/VA	Ford	1976	45	3-axis	2200
DSCS-III	GE	1977	89	3-axis	2500

[a]Price per spacecraft, including on-orbit performance incentives, in millions of 1983 dollars.

V. PROGRAM OUTCOMES

We next consider how the actual outcomes in program schedule, system performance, and price compared with the expectations laid down at the beginning of full-scale development.

In previous sections of this report, we compared the overall INTELSAT and Air Force communication satellite programs. However, when we compare program outcomes such as cost, schedule, and performance, the programs must be reasonably comparable or else the comparisons are meaningless. In the following analysis we will therefore focus on comparisons within each of two commercial/military satellite pairs: the DSCS-II program will be compared with the ISAT-IV program, and the DSCS-III program will be compared with the ISAT-V program.[1] Summary characteristics for each pair are shown in Table 14. Similarities and differences among the two programs in each pair are discussed in more detail in App. E.

DEVELOPMENT SCHEDULES

One frequent criticism of military acquisition practice is that development schedules are extended to an unnecessary degree, resulting in delayed fielding of the equipment and a consequent dilution of its military effectiveness. It is sometimes further argued that the length of development schedules is increasing over time, leading to higher development cost and later availability dates than are absolutely necessary. Numerous studies have been conducted on this topic,[2] but they have tended to focus on aircraft and missiles. This study provides an opportunity to examine one element of the broader set of issues: was there a significant difference in the time required to develop military and commercial communication satellites that were at least roughly similar?

Table 15 summarizes schedule data. Relevant dates are shown for the first satellite to be accepted for launch in each series. In all cases, the scheduled delivery date specified at the beginning of full-scale development (FSD) was subsequently modified through contract changes, usually to account for corresponding changes in the contracted scope of work. Thus, any delivery schedule penalties would have been based on the revised date. However, the DSCS-III program carried no contractual delivery schedule penalties, and extension of the scheduled delivery date seems to have been at least partly a simple recognition of fact rather than a true reflection of changes in scope.

These data are shown in graphical form in Fig. 2, where no distinction is made about *why* a schedule slipped. Only the original scheduled delivery date and the actual acceptance date are shown for each system. It can be seen that all programs failed to meet their original delivery date for one reason or another. It is also clear that in terms of actual delivery date, Air Force systems tended to take longer than comparable INTELSAT systems, but the difference was only a few percent in each case and hardly seems significant. Thus, evidence from this limited sample indicates that INTELSAT and the Air Force differ little in the time required to develop a communication satellite.

[1] Information on other INTELSAT programs is included in this section as a documentation convenience even if it does not contribute to the pairwise comparisons.

[2] See, for example, G. K. Smith and E. T. Friedmann, *An Analysis of Weapon System Acquisition Intervals, Past and Present*, The Rand Corporation, R-2605-DR&E/AF, November 1980.

Table 15

DEVELOPMENT SCHEDULE COMPARISONS

System	Contract Date	Scheduled Delivery Date[a]	Actual Delivery Date	Actual Launch Date	Lead Time (mo.) from FSD Start: To Scheduled Delivery	To Actual Delivery	To Actual Launch
DSCS-II	2-28-69	1-15-71[b] 3-26-71[c]	10-71c	11-2-71	23 25	32	33
ISAT-IV	10-18-68	8-18-70 12-2-70[d]	12-2-70	1-25-71	22 26	26	27
ISAT-V	9-21-76	6-21-79 12-8-79[e]	10-21-80	12-6-80	33 39	49	50
DSCS-III	2-1-77	7-1-79 6-30-81[f]	6-30-81	10-82	29 53	53	68[g]

[a]Original scheduled delivery date of first flight satellite, unless otherwise noted.

[b]Delivery of first pair.

[c]Revised per change number P00069 to the DSCS-II initial contract.

[d]Revised per Ammendment #12 to the ISAT-IV contract.

[e]Revised per Ammendment #14 to the ISAT-V contract.

[f]Revised per change number P00233 to the DSCS-III development contract.

[g]After acceptance, satellite was placed in storage, partly because of a shortage of Titan III boosters and partly because DSCS II satellites were functioning well and satisfying demand.

ON-ORBIT PERFORMANCE

The general performance goals for the four satellite models compared here are summarized in App. E. One important measure of comparison is the extent to which the performance goals were achieved.

To a large extent that question can be answered by examining on-orbit lifetime. Communication performance, or antenna pointing, or station-keeping, or some other performance parameter can degrade somewhat without completely destroying the utility of the system, and such degradations are generally not a serious problem. To a first approximation, a communication satellite either works or it doesn't. In this study, system performance is measured by the period of time the satellite worked according to its performance specifications.[3] If a component, such as a traveling-wave-tubeamplifier, failed and a redundant unit was substituted,

[3]Information on the performance of INTELSAT satellites was obtained from the monthly publication, *INTELSAT Satellites In-Orbit Technical Status*, available from the Public Affairs office of COMSAT. The monthly reports describe the status of each INTELSAT satellite in orbit, including whether it is in active service or in reserve status, the type of traffic it is carrying, its orbit location, and any technical difficulties that might have been experienced during that month.

Performance of DSCS satellites was obtained from the *DSCS Satellite History Record*, prepared by Aerospace Corporation, together with supplementary data supplied by the DSCS project office.

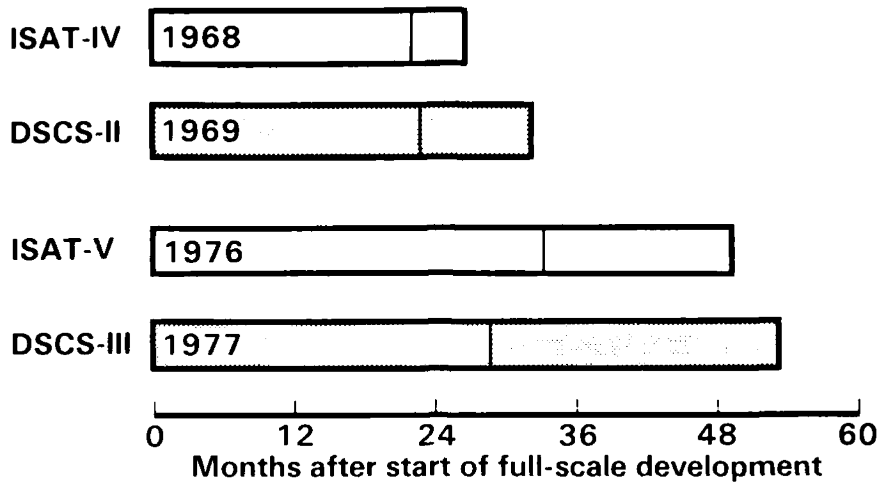

Fig. 2—Development durations

the event was ignored in our computations because the spacecraft still performed its specified mission.

The performance results are shown in Fig. 3. The filled portion of each bar represents the period of time the satellite performed substantially to specifications. Gaps in a bar represent periods when the satellite was inoperable, almost always because the antenna failed to despin and could not be pointed at a ground station. The right-hand end of the bars are terminated in any of three ways: (1) A simple termination (as on four of the first five DSCS-II satellites) means that the satellite failed at that time and further operation was impossible. (2) The short vertical mark at the end of the first five ISAT-IV satellites indicates that INTELSAT declared those satellites "retired" because they were no longer needed for revenue service, even though they retained at least some of their communications capability. (3) The arrow head terminating most of the bars indicates that as of mid 1983 those satellites were still functioning in orbit. The right-hand brackets indicate the end of the design life for each satellite.

It can be seen from these displays that the first three DSCS-II satellites experienced shorter-than-expected lifetimes, with almost all of the major failures attributed to mechanical problems with despinning and pointing the antennas. After resolution of those early problems, the remaining satellites display an almost unblemished record of satisfactory operation. The ISAT-IV/IVAs, in contrast, had no major problem. The DSCS-III and ISAT-V satellites that have been launched are operating satisfactorily.

Although the Air Force systems experienced some initial problems, and have fewer satellites, there is no basis in the data to say one class performed better than the other.

PROGRAM PRICES

As noted in Sec. I of this report, earlier studies have suggested that military communication satellite programs tended to cost more than their commercial counterparts, and that the military programs tended to experience greater cost growth over the original estimates. Here we compare the programs in terms of both characteristics.

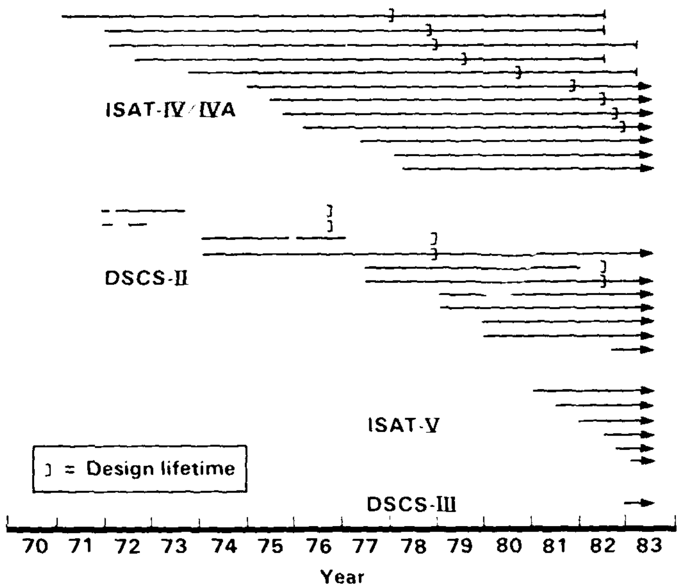

Fig. 3—INTELSAT on-orbit lifetimes

Comparing Prices

In Sec. II, we discussed the full prices of the DSCS and INTELSAT satellites, and Table 1 gives estimates of the full, *on-orbit* price of the systems, all in 1983 dollars.[4] Unfortunately, prices for the different spacecraft are *not generally comparable* because they each have different capabilities and represent different technologies.

Detailed analysis of the separate systems, however, reveals that one pair, the DSCS-II and the ISAT-IV and -IVA systems, is similar enough to support at least rough price comparisons.[5] These two satellite systems were procured over the same time period and incorporate roughly the same technology. While DSCS-II did include minor requirements for nuclear hardening and antijam capabilities not provided in the ISAT-IV satellites, those extra capabilities appear to have had only a modest effect on development or production cost, and experts suggest that the prices of the two satellite models should be within a few percent of one another.

Table 16 reviews our estimates of the prices paid for these satellites. Per-satellite prices (total program price divided by the number of spacecraft produced) are shown separately for the two DSCS-II contracts and for the two ISAT-IV subprograms. Again, we show prices for the spacecraft contracts, for on-orbit performance incentives, and for launches. Since the launch prices paid by the DSCS SPO do not represent the full costs of those launches either to the Air Force or to the U.S. government (see Appendix B), price comparisons should focus on the spacecraft plus incentives subtotal.

[4]Details on the estimation of these prices appear in Apps. A and B.
[5]Comparative details on DSCS-II and ISAT-IV/A are given in App. E.

Table 16

COMPARING DSCS-II AND ISAT-IV/A PRICES
(Program price per spacecraft in millions of 1983 dollars)

	DSCS-II			ISAT-IV/A		
Item	Initial	Replenish-ment	Total	-IV	-IVA	Total
Spacecraft	39	31	34	30	35	32
Incentives	0	2	1	8	6	7
Subtotal	39	33	35	38	41	39
Launch	35	20	26	44	41	43
Total	73	53	60	83	82	82

SOURCE: Tables A.15 and B.13.
NOTE: Detail may not sum to total because of rounding.

Table 16 indicates that the DSCS-II satellites were slightly cheaper to procure than were the ISAT-IV/A satellites—perhaps as much as 10 percent cheaper. If the performance requirements of these systems are in fact roughly comparable, the results suggest that the Air Force acquisition was managed as least as efficiently as that by INTELSAT.

Price Change

Perhaps the most frequent criticism of military procurement is that prices (or the "cost to the government") tend to grow much higher than the original estimates. Such growth is well documented, and the evidence suggests that the prices of weapon system programs tend to grow by 5 or 6 percent per year throughout the acquisition phase.[6] It is also well known, although usually not discussed in military procurement analyses, that many commercial programs also experience large price growth (nuclear-powered electricity generation stations are an example, but items as mundane as stadiums and office buildings often qualify).

The phrase "price growth" usually carries a pejorative connotation, yet there are often valid reasons for changes in program price. In this study, we prefer to use the term price change, which we define as any difference between the original contract price and the final contract price. The overall price change was summarized earlier in Table 3 as part of our discussion of contract types. Here we more carefully distinguish between the various sources of change. Although the available records do not permit a detailed categorization, they do permit price changes to be divided between two sources:

1. The procurement of additional spacecraft.
2. All other price changes, including the amounts charged for development work requested (or agreed to) by the customer but not included in the original contract, as well as any growth that was charged against cost incentive clauses in the contract.

[6] For an overview of weapon system cost growth, see E. Dews, G. K. Smith, A. A. Barbour, E. D. Harris, and M. A. Hesse, *Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s*, The Rand Corporation, R-2516-DRE, October 1979.

Measured in this aggregate way, price change is more susceptible to comparison than is absolute price. A summary of price change experience to date is shown in Table 17. In general, nearly all of the price change associated with INTELSAT contracts has involved the purchase of additional spacecraft (note the smaller entries in the right-side column)[7]. The relative magnitude of design changes, modifications, added tests and other program changes is quite small. Only ISAT-V acquired much improved subsystems after the originally contracted development work.

The two Air Force programs have a somewhat different distribution. Their original contracts represented a smaller portion of the overall funding, with procurement of additional spacecraft the major program element. That was not unexpected; Air Force programming documents clearly indicated the intention of buying additional spacecraft in both the DSCS-II and DSCS-III projects. However, "other" changes represented a much larger percentage of the total Air Force programs than was typical of the INTELSAT programs.

Table 18 gives additional details on price changes for the most directly comparable pairs of programs—ISAT-IV/A vs. DSCS-II and ISAT-V vs. DSCS-III. Contract prices are as of September 1983 (the end of the government fiscal year).

The upper portion of the table shows the original contract, the price that can be attributed to subsequent procurement of additional spacecraft, and other (generally nonrecurring) expenditures, together with the totals to date. The lower portion shows additional details on the source of "other" expenditures (more information is in Apps. A and B).

Let us assume that a desirable goal for project management would be to complete the program specified in the original contract without any change in price, and that all subsequent expenditures should be limited to recurring costs of building additional spacecraft. That is, admittedly, an idealized goal that does not accommodate technical uncertainty or changing operational needs, but it is reasonably close to the model implicitly assumed by government procurement regulations and public expectations. Measured against such a model, the "other" expenditures are liable to be interpreted as a rough measure of project management ineffectiveness. When we focus on those values (bottom line in Table 18), we find two interesting

Table 17

SUMMARY OF SPACECRAFT PRICES AND PRICE CHANGES

	Percent of Total Price Attributable to		
System	Original Contract	Additional Spacecraft	Other Changes
DSCS-II	23	59	18
ISAT-IV/IVA	62	35	3
DSCS-III	14	59	28
ISAT-V/VA	40	50	10

SOURCE: Tables A.2, B.3, and B.4.

[7] It is clear that at least some subsequent procurement was anticipated, and the INTELSAT contracts carried option clauses covering additional production items.

Table 18

SPACECRAFT PRICE CHANGE SUMMARY

Item	ISAT IV/IVA	DSCS II	ISAT V/VA	DSCS III
Original contract	30	23	41	13
Number of spacecraft	(4)	(6)	(7)	(2)
Additional spacecraft				
Price	68	59	50	59
Number	(10)	(10)	(8)	(5)
Other changes	2	18	9	28
Total contract	100	100	100	100
Further Detail				
Maritime communication system			5	
AFSATCOM				3
Battery improvements			1	
Apogee motor improvements			1	
Amplifier development		3		2
Additional tests	1			
Launch vehicle integration				10
Storage and retest		6		1
Batson II integration				1
STS avionics modifications				1
Launch operations		1		
Miscellaneous	2	6	2	6
Price increases		2		4
Subtotal (other)	2	18	9	28

SOURCE: Tables C.4 through C.6, C.14 through C.17, B.3, and discussion with program personnel.

results. First, the magnitude of price change due to "other" causes appears to differ between the INTELSAT programs and the Air Force programs. Such change in the ISAT-IV/IVA is only 2 percent, compared with 18 percent for DSCS-II. Likewise, price change due to "other" causes is 9 percent for ISAT-V, compared with 25 percent for DSCS-III.[8]

The second observation is that both organizations tend to be increasing prices for reasons other than procurement of additional spacecraft. Successive INTELSAT programs went from 2 to 9 percent, and successive Air Force programs went from 18 to 25 percent. Although it is unsafe to extrapolate on the basis of such limited experience, the direction and rate of the trend should serve at least as a caution to program managers.

[8]More DSCS-III spacecraft will probably be bought, so the magnitude of the "other" expenses will probably change, both in absolute magnitude and as a percent of basic price. The expenditure history in that program does not yield any clues on how those future buys might affect additional expense as a percent of basic price.

VI. RESULTS AND CONCLUSIONS

This study compared the acquisition of commercial and military communication satellites and attempted to answer three general questions:

1. Are there significant differences in the manner in which commercial and military programs are managed?
2. Are there significant differences in the outcomes of the commercial and the military programs?
3. Can any identified differences in outcomes be traced to differing management methods? Or is there any other basis for identifying possible improvements in the procedures used by the Air Force in managing its acquisition of communication satellites?

MANAGEMENT PRACTICES

We compared the management practices of INTELSAT and the Air Force in terms of the kinds of contracts used, the use of incentive clauses, how system performance and test programs were specified in the contracts, the organization and activity of the program management staffs, and the number and type of program changes experienced. We found significant differences between the commercial and military sectors only in the incidence and scope of contract changes and in the use of incentives.

Managing Contract Change

Both organizations employ fixed-price contracts for almost all development and production activities. Furthermore, in each program the initial contract is signed only after an extensive, competitive concept formulation phase. However, in almost all cases that initial contract covers less than half the overall value of the program as it finally evolves. In the programs we examined, the initial contract was always amended to increase the scope of activity. And often follow-on contracts were negotiated for additional procurement (and sometimes development) work.

Both the number and the dollar magnitude of the changes were considerably greater in the Air Force programs than in comparable INTELSAT programs. Such changes and contract extensions effectively negated at least some of the cost control inherent in fixed-price contracts, and the Air Force appears to have been less effective than INTELSAT in maintaining the *opportunity* for contractual price control. However, in the one instance where the Air Force and INTELSAT produced roughly comparable systems, we find no significant difference in total program price.

The Use of Incentives

Another difference in contracting practices is in the use of incentives. Both organizations apply a combination of schedule and on-orbit performance incentives in their contracts, and the Air Force also applies cost and award incentives. INTELSAT tends to make its incentives

account for a larger fraction of total program price than does the Air Force, and tends to put special emphasis on performance incentives. The Air Force tends to emphasize cost incentives and, more recently, award fees.

However, except in the details of the incentive clauses, the two approaches have similar objectives and seem to have produced similar outcomes. The incentives are all designed to affect a contractor's incremental decisions when, during the course of an acquisition, he finds he can perform some tasks better or worse than anticipated. The incentives encourage him to incur the extra costs necessary to produce a well-performing satellite if the original design turns out to have been inadequate; or, conversely, they encourage him to incur the extra costs that will incorporate marginal improvements in quality and performance when those appear to be attainable. INTELSAT relies on relatively large on-orbit incentives to support these objectives; the Air Force uses a combination of cost and on-orbit incentives. However, the cost-sharing incorporated in the cost incentives, because it reduces the contractor's incremental costs, probably makes the Air Force's incentives as forceful as INTELSAT's.

The evidence we have examined validates this observation and indicates that the two approaches are producing similar outcomes: after initial design problems are overcome, on-orbit lifetimes for both Air Force and INTELSAT spacecraft appear to be equaling or exceeding design life; on the other hand, costs and schedules are often not met. In the Air Force programs, the price often grows to the ceiling value. In both Air Force and INTELSAT programs, follow-on buys are priced higher than we would expect; and in both programs schedules seem to be extended without regard to associated penalties. These findings suggest that both the Air Force and INTELSAT have found effective ways of indicating to their contractors that they wish to procure well-performing spacecraft even if that requires adjustments to the costs and schedules.

PROGRAM OUTCOMES

Our comparison of the outcomes of Air Force and INTELSAT programs in terms of development schedule, on-orbit performance, price, and price growth indicated few differences except in price growth.

Among pairs of military and commercial systems that were contemporary and that represented comparable levels of technical difficulty, the development durations, measured from the start of full-scale development to the delivery of the first flight spacecraft, are similar. Some modest extension in the originally scheduled development duration is typical of both military and commercial programs. Our sample is limited, but it does not support the common assertion that military systems typically take unnecessarily long to develop.

In all but the earliest programs the Air Force imposed performance requirements that differed from those required by INTELSAT—the Air Force requiring less voice and data throughput but demanding some amount of nuclear hardening and antijam capability, and usually more station-keeping autonomy. This makes it difficult to compare system capabilities. We are able, however, to judge system performance by observing how long each of the systems operated satisfactorily, *in terms of its particular requirements*, after being put into orbit. We find that both INTELSAT and the Air Force suffered reliability problems during their earlier programs, but after those initial problems were resolved both organizations have produced satellites that are meeting and exceeding their lifetime goals. We find no basis in our comparisons to say one or the other organization has a better product in a comparable time period.

One set of spacecraft possessed sufficiently similar performance requirements to permit a direct price comparison—the ISAT-IV designs were similar to the DSCS-II designs in most major respects, and the programs were started within a few months of each other. The DSCS-II included some modest hardening and encryption requirements, but they do not appear to have been large cost drivers on the design. The average price per spacecraft (including both development and production funds) for these systems differed by only a few percent.

All programs in this study experienced some degree of price change beyond that associated with the purchase of follow-on spacecraft, with the Air Force systems sustaining substantially more change than the INTELSAT systems. The greater price change appears to be directly linked with the Air Force tendency to make more contract changes (as noted above). It is interesting, however, that although the Air Force DSCS-11 price change was 19 percent, compared with 2 percent for the ISAT-IV, the final overall per-satellite cost of the Air Force program was slightly lower than that of the INTELSAT program. This suggests that, in this case at least, the Air Force program may have been underpriced and that the price change was at least partly an evolution to a more realistic price.

CONCLUSIONS

What can we conclude from these results in terms of improving Air Force management effectiveness? Despite the small sample size and the inevitable differences in system performance requirements between the military and commercial sectors, we are most struck by the remarkable similarity between the management practices used by INTELSAT and the Air Force and the success of their acquisition programs. Both organizations sponsor the development of technologically advanced systems, and, after overcoming problems in the earlier designs, all of the products appear to be performing well and satisfying customers.

In comparing acquisition practices, we could categorize the INTELSAT acquisition process as heavily performance oriented. The Air Force process is also primarily performance oriented, but in addition it allocates significant attention to cost and process control. This difference in emphasis probably stems from the difference in staff experience and continuity in the two organizations and from the fact that INTELSAT's chain of command is significantly shorter, with the corporation's top management officials directly involved in most financial and many technical decisions.

In comparing acquisition outcomes there is a temptation to refute earlier allegations that Air Force communication satellites cost more than their commercial counterparts. However, any such argument would be based on a single data point—the ISAT-IV and DSCS-II comparison. That was the only opportunity we had to compare systems that were roughly similar in design and performance. In the next-generation systems, large differences in performance requirements separate the ISAT-V and the DSCS-III, and the DSCS-III is costing nearly twice as much. Judging whether or not that higher price is justified by the differing performance requirements is beyond the scope of this study.

The Air Force does, however, tolerate many more contract changes than does INTELSAT, perhaps reflecting the greater uncertainty associated with military requirements. The Air Force's perception of the enemy threat and the ability of alternative systems to counter it is less stable than INTELSAT's perception of future commercial communications requirements. Or it may be because the Air Force rotates its personnel more widely and has a longer chain of command with, consequently, less continuing authority resting with program managers. Most likely both causes contribute.

The INTELSAT approach to satellite procurement—emphasizing delivery and performance—is characteristic of commercial practices. Corporations procure equipment to generate revenue, and they want that equipment to be delivered on time, at the agreed price, and they expect it to work immediately. Late delivery or faulty performance reduces profits. INTELSAT, in conducting its business of worldwide satellite communications, conducts major procurements of both satellites and ground equipment, and has developed an extensive and sophisticated organization to manage procurements.

Air Force acquisition practices, in contrast, have evolved in response to the generalized environment that surrounds most large governmental purchases. The Air Force buys diverse types of costly, sophisticated equipment and constantly reassesses its possibilities and priorities in response to changes in technologies, intelligence concerning its need for various systems, and its budget. In particular, the size and composition of the overall Air Force acquisition budget ensure that communication satellites are seldom given top priority for dollars or for management overview.

In this environment it is unreasonable to expect military satellite acquisitions, even when well thought-out and fully specified at the time of contract award, to proceed smoothly and without change. Furthermore, management practices such as multiyear or full-package procurement, which attempt to lock in initial specifications and schedules, may actually hinder attainment of the wider, constantly evolving needs of the Service. Nevertheless, just as there a place for those methods in carefully selected situations, there is should be a place for some of the performance-oriented INTELSAT management practices.

Contracting methods that emphasize performance, such as firm-fixed-price contracts and achievement-based progress payments, should work as well in military applications as in commercial ones. Restructuring staffing assignments to strengthen program continuity and institutionalize learning, to the extent possible in the military environment, would help in the design and control of future as well as current acquisitions. And so would the adoption of organizational arrangements that allocate authority to program managers in direct proportion to the responsibility they hold.

Appendix A

THE PRICE OF INTELSAT'S COMMUNICATION SATELLITES

This appendix gives the complete prices for the space segments of INTELSAT's commerical communication satellite systems, including the contract prices for the basic satellites, the amounts paid by INTELSAT[1] to the spacecraft suppliers for schedule and on-orbit performance incentives, and the prices paid for launching the satellites. Our objective is to present the prices paid for commercial communication satellites in a form that will permit comparison with the prices of roughly comparable military communication satellites.

We concentrate solely on the "price" of these systems because we have information only on the payments from INTELSAT to the several suppliers of spacecraft and launch services. We do not know how much any of the items actually "cost," either to the suppliers (since they were usually not required to report their costs to INTELSAT under the fixed-price contracts they signed) or to the nation.

Most of the following information has been taken from INTELSAT contracts and contract amendments, from system descriptions and summaries obtained from INTELSAT, or from third parties such as the DMS Market Intelligence reports. Less information is available on the ISAT-I, -II, and -III systems than for the others, so those systems will receive less emphasis.

SPACECRAFT PRICES

We begin by examining the contracts between INTELSAT and the spacecraft suppliers. These contracts cover not only the development and production of communication satellites but also such items as spares, ground support and control equipment, and launch support services. We first discuss the contracts as they were written, usually in then-year dollars; we then convert the prices for all of the systems into common 1983 dollars in order to compare them more carefully.

INTELSAT provided us with a summary statement of basic delivery prices, launch costs, and (maximum) incentive payments for all of their systems, including ISAT-I. Information from that sheet is reproduced as Table C.1 in App. C. Tables C.2 through C.7 contain item and price information from the ISAT-II through ISAT-VI contracts.

The summary statement and contract information are compared in Table A.1. Spacecraft prices—including all contractual payments from INTELSAT to the spacecraft supplier covering delivered spacecraft, schedule incentives or penalties, storage costs, and other deliverable items (but excluding all on-orbit performance incentives and penalties)—as we interpreted them from the summary sheet provided by INTELSAT are compared with similar information extracted from the contracts and amendments.

The prices from the INTELSAT fact sheet probably come closer to the prices actually paid than do the prices stated in the contracts. The contracts contain entries such as charges fro storage which cannot be determined ahead of time, and penalties for items that are not

[1]Although COMSAT Corporation acted as the contracting and management agency in the earlier programs, we refer to them as INTELSAT contracts and programs throughout this report.

Table A.1

INTELSAT SPACE PROGRAM PRICES
(Millions of then-year dollars)

System	Program Prices: Fact Sheet	Program Prices: Contract Analysis
ISAT-I	7	
ISAT-II	14	14
ISAT-III	48	47
ISAT-IV	80	81
ISAT-IVA	107	102
ISAT-V&VA	439	436
ISAT-VI	527	523

SOURCE: Tables C.1 through C.7.

delivered on schedule; we do not know the ultimate prices of these charges and penalties. The more detailed information in the contracts is, however, used in some of the analyses and discussions below.

Table A.2 summarizes our information on the composition of the total prices for the INTELSAT systems. Three points are of particular interest. The first is the steady increase in nominal prices over time. (Later we will factor inflation from these estimates to trace the "real" trends in spacecraft prices and to compare those with changes in capability.) The second is the small, though not necessarily insignificant, entries in the right-side columns. Nearly all of the price change associated with these contracts has resulted from the purchase of

Table A.2

SUMMARY OF INTELSAT SPACE PROGRAM PRICES AND PRICE CHANGES

System	Total Flight Units	Total Price[a]	Percent of Total Price Attributable to: Original Contract	Added Spacecraft	Mods & Changes	Pricing Changes	Other
ISAT-I	2	7	ni	ni	ni	ni	ni
ISAT-II	4	14	76	22	2	-	-
ISAT-III	8	47	68	27	-	4	1
ISAT-IV	4	81	68	28	2	-	1
ISAT-IVA	6	102	58	41	2	-	-1
ISAT-V&VA	15	436	40	50	8	-	2
ISAT-VI	5	523	99	0	1	-	-

SOURCE: Tables C.1 through C.7.
NOTE: "ni" indicates no information is available.
"-" indicates less than 0.5 percent.

[a]Prices are in millions of then-year dollars.

additional spacecraft. The relative magnitude of the design changes, modifications, and added tests is quite small. Only ISAT-V acquired much improved subsystems after the originally contracted development work; and only ISAT-III explicitly increased the final price of several already-priced satellites. Finally, we note that ISAT-VI is still in the early stages of its contract, and past experience suggests that additional changes will occur.

LAUNCH PRICES

Launch vehicles, systems integration, and other items required for the successful launch of communication satellites are contracted for separately from the spacecraft. We have not seen the INTELSAT contracts for these items; however, the INTELSAT fact sheet referred to above and abstracted in Table C.1 contains summary information on spacecraft launches. We combined that INTELSAT data with launch information from the latest TRW Space Log to produce Table A.3.

The spacecraft contracts contain items relating to launch services and, at least since ISAT-III, each of the INTELSAT satellites comes equipped with an apogee motor to provide the final orbital-insertion burn. The apogee motors are priced separately in the contracts for ISAT-III and ISAT-IV, and amount to 4 percent and 3 percent of the original price (or 3 percent and 2 percent of the final price), respectively. Launch services seem always to be priced separately, and amounted to 4 percent of the final price for ISAT-II and ISAT-III, 2 percent for ISAT-IV, and 1 percent for ISAT-IVA and ISAT-V. We will consider these apogee motor and launch service items as part of the spacecraft contracts.

Table A.3

LAUNCH DATES AND PRICES
(Millions of then-year dollars)

	INTELSAT Program						
Item	I	II	III	IV	IVA	V/VA	VI
Launch date	1965	66/67	68/70	71/75	75/78	80/?	86/?
Total launch price	4.4	17.9	41.6	143.9	144.4	694.6	
Total launches	1	4	8	8	6	15	
$/launch	4.4	4.5	5.2	18.0	24.1	46.3	
Successful launches	1	3	5	7	5		
$/orbiting spacecraft	4.4	6.0	8.3	20.6	28.9		

SOURCE: Table C.1 and TRW Space Log.

NOTE: Two ISAT-Is were procured but only one was launched. Five ISAT-2s were procured but only four were launched.

SCHEDULE AND PERFORMANCE INCENTIVES

The INTELSAT contracts all contain some type of incentive for on-schedule delivery of the spacecraft and for satisfactory on-orbit performance. The schedule incentives usually take the form of penalties for late delivery, but several contracts also call for bonuses to be paid for spacecraft delivered ahead of schedule. Performance incentives are usually positive, although they take many forms, and some involve paybacks if subsequent performance does not continue to be satisfactory. These incentives are discussed below.

Schedule Incentives

INTELSAT typically assesses penalties against its spacecraft suppliers if the first or second satellites are delivered later than either the date specified in the original contract or some amended or negotiated later date. There is always a provision for "excusable" delays and always a maximum period or dollar amount limiting the penalties. If delivery is delayed beyond that period for an inexcusable reason, the contract can usually be terminated.

Table A.4 summarizes the schedule incentives written into the contracts for the ISAT-II through ISAT-VI spacecraft. The incentives for the six systems are similar in structure but differ in detail and severity. The provisions written into the original ISAT-II contract called for a fairly modest penalty of $5,000 per day for the late delivery of either of the first two flight spacecraft, with the penalty limited to $150,000 per spacecraft. Later, when a fifth flight spacecraft was purchased, an incentive/penalty was attached worth $6,000 to the contractor for every day that the spacecraft was delivered early or costing him $6,000 for each day it was late. Again, the limit was 30 days, but in this case it applied in either direction, and the dollar amount was thus limited to plus or minus $180,000.

The original ISAT-*III* schedule *penalties applied to all spacecraft* and were valued at $5,000 per week, rather than the $5,000 per day of the ISAT-II penalties. The coverage period of eight weeks limited the maximum penalty for the ISAT-IIIs to $40,000 per satellite. For the F-7 and F-8 spacecraft purchased later, however, the penalties were structured differently. For these spacecraft the first five months (five and one-half for F-7) of delay were without penalty. If the delay was longer, the contractor was required to pay $250,000 in damages to INTELSAT immediately and then an additional $50,000 per month for each additional month of delay up to a maximum of $500,000 total for each spacecraft. There were no bonuses for early delivery.

The ISAT-IV contract contained schedule penalties only for the first two satellites of the first buy, but the potential maximum penalties were much greater than before. If the first flight spacecraft was delivered more than 143 days after its final due date, the contractor was liable for $7,000,000. Late delivery of F-2 could be penalized by another $1,000,000, or 7 percent of its price.

The structure of the late delivery penalties for ISAT-IVA were similar to those for ISAT-IV but the amounts were less, and the penalties for ISAT-IVA were extended to the first two spacecraft of the second buy, as in the earlier contracts. The maximum was $1,800,000 for F-1, $200,000 for F-2, $1,350,000 for F-4, and $200,000 for F-5.

ISAT-V went back to the simpler incentive structure. The first 7 spacecraft could earn a bonus if they were delivered up to a month early. The delivery schedule of each spacecraft was based on the actual delivery date of the previous one, hence early delivery of one affected all subsequent deliveries. This bonus feature was not continued for spacecraft eight through 16. On the other hand, each spacecraft could incur a penalty for each day of delay, up to 90 days.

Table A.4

SCHEDULE INCENTIVES IN INTELSAT CONTRACTS

	Bonus		Penalty	
Item	Per Day	Max. Days	Per Day	Max. Days
ISAT-II				
F-1/2			$ 5,000	30
F-5	$ 6,000	30	6,000	30
ISAT-III				
F-1/6			714	60
F-7/8			1,667	300[a]
ISAT-IV				
F-1			20,000	30
			40,000	30[b]
			70,000	73[b]
			20,000	1[b]
F-2			1,000,000	1
ISAT-IVA				
F-1			5,000	30
			10,000	30[b]
			17,000	73[b]
			92,000	1[b]
F-2			200,000	1
F-4			4,000	30
			8,000	30[b]
			12,750	73[b]
			46,500	1[b]
F-5			200,000	1
ISAT-V/VA				
F-1/7	12,780	30	12,780	90
F-8			13,993	90
F-9			11,772	90
F-10/12			16,664	90
F-13,16			12,968	90
ISAT-VI				
F-1/5			13,333	30[b]
			40,000	90

SOURCE: INTELSAT contracts and amendments.

[a]Penalty for ISAT-III, F-7 and F-8 did not commence until delivery was five months late; then a flat charge of $250,000 was imposed and daily penalties began.

[b]Penalty commenced after a previous penalty period ended.

ISAT-VI then continued the recent trend toward simplicity. Early delivery of ISAT-VI spacecraft earn no bonus, but late delivery can result in penalties of up to $4,000,000 if a spacecraft is delayed over four months.

We put these schedule incentives in perspective in Table A.5, which expresses the maximum bonus and penalty that could be earned by the various spacecraft as a percent of their purchase price. As noted before, the penalties attached to late delivery of the first ISAT-IV were substantially greater than the others; they could be half of the basic price of the ISAT-IV spacecraft, whereas most other spacecraft penalties were limited to 10 percent or less. The more recent tendency seems to be to set these schedule penalties at 4 or 5 percent of the spacecraft price.

Discussions with INTELSAT officials indicate that perhaps half of the schedule penalties were actually realized. They report that (1) ISAT-III was at least eight weeks late and full delivery penalties were assessed on each satellite; (2) ISAT-IV was delivered in compliance with an amended schedule, which was some 10-11 weeks later than the original schedule because of other contract changes, but no penalties were paid; (3) ISAT-IVA also slipped slightly because of other changes and no penalties were assessed; and (4) long delays in ISAT-V delivery resulted in the assessment of maximum schedule penalties.

On-orbit Performance Incentives

All of the INTELSAT spacecraft contracts we examined had provisions for on-orbit performance incentives contingent on successful operation of the communication mission of the satellite. The incentives are designed to encourage development and manufacturing practices that increase the probability that the satellites will operate successfully throughout their design life. They also are intended to encourage the manufacturer's cooperation and support for the initial on-orbit checkout and for malfunction analysis and corrective action identification throughout the life of the satellite.

Performance incentives are typically paid:

- If the spacecraft is injected into the correct orbit and operates successfully for an initial period.
- If the spacecraft continues to operate satisfactorily.
- If the spacecraft is accepted by INTELSAT but not launched within 90 days.
- If the booster fails to place the spacecraft into the proper geostationary transfer orbit and attitude or if the spacecraft is damaged by its launch vehicle.

Incentive payments may be positive (e.g., giving the contractor bonus money for each operating period, usually specified as 30 or 90 days (see Table A.6), that the satellite operates successfully) or negative (e.g., the contractor pays the customer a penalty for each period the satellite fails to operate successfully), or a combination of both. INTELSAT typically assesses penalties only if it has paid bonus money "up-front."

Each of the INTELSAT contracts contains a section defining operation which is considered satisfactory for the payment of performance incentives. If a spacecraft does not perform up to these specifications and therefore is held out of service, no incentives are paid. Typically, if the specifications are not fully met but INTELSAT considers the satellite capable of carrying commercial traffic, some portion of the incentive is paid. The level of less-than-full incentives to be paid is usually open to negotiation, although the ISAT-III contract contained a formula specifically designed for that purpose.

Table A.5

SCHEDULE INCENTIVES AS PERCENT OF SPACECRAFT PRICES

Item	Estimated Spacecraft Price	Maximum Incentive as Percent of Price: Bonus	Maximum Incentive as Percent of Price: Penalty
ISAT-II			
F-1 and 2	2.7		6
F-5	2.6	-	7
ISAT-III			
F-1 - 6	5.9		1
F-7	3.9		13
F-8	7.5		7
ISAT-IV			
F-1	14.1		50
F-2	14.1		7
ISAT-IVA			
F-1	19.9		9
F-2	19.9		1
F-4	14.2		10
F-5	14.2		1
ISAT-V/VA			
F-1/7	30.8	1	4
F-8	27.3		5
F-9	23.0		5
F-10/12	33.0		5
F-13/16	23.8		5
ISAT-VI			
F-1/5	104.5		4

SOURCE: INTELSAT contracts and amendments.

NOTE: For this table we estimated separate prices for the spacecraft associated with separate buys. In general, we associated only items specifically linked to the add-on spacecraft with the second (or third) buy; all remaining items were associated with the first (basic) buy. This procedure was clearcut for ISAT-II and ISAT-III, but more complicated for ISAT-IV, ISAT-IVA, and ISAT-V. Consequently, the entries in the table should be viewed only as rough estimates.

Several areas of spacecraft operation are usually affected by the incentives. First, the apogee motor and spacecraft control systems must insert the satellite into geostationary orbit properly and then maintain the satellite's position and attitude. Second, the communication subsystem must meet its basic design specifications. And third, the batteries and charging system must perform properly so that the satellite can function properly during eclipse periods.

Several of the more important characteristics of the incentive provisions for INTELSAT satellites are shown in Table A.6.

Each INTELSAT contract we analyzed had a provision for the payment of positive on-orbit incentives. The latest contract, that for the ISAT-VI, contains a negative provision or warranty as well. The dollar amounts of the incentives for the first spacecraft in each series are summarized in Table A.7.

The dollar incentives called for under these contracts increase steadily as we move from one contract to another, as do the delivery prices.[2] The increase is primarily the result of increasing communications capability and inflation over the 20-some years that the contracts cover. Later in this appendix we will factor inflation out of the satellite prices and compare

Table A.6

PERFORMANCE INCENTIVE SCHEDULES FOR INTELSAT SPACECRAFT

	Length of Performance Period		
System	Initial (days)	Total (years)	Payment Schedule
ISAT-II	30	4	Monthly payments
ISAT-III	30	6	Monthly payments
ISAT-IV			
F-1–4	30	7	Monthly payments
F-5–8	30	7	Full payment after 30 days; refunds for later failure
ISAT-IVA	30	7	Full payment after 30 days; refunds for later failure
ISAT-V/VA	[illegible]	7	Monthly payments after 1st qtr
ISAT-VI	90	10	Penalty assessed at end of 1st year if spacecraft fails initially or during that year Payment for years 1-5 made at end of year 1; refunds for failure during years 2-5; monthly payments during years 6-10

SOURCE: INTELSAT contracts and amendments.

[2] Throughout this discussion we define "delivery price" as the program unit price of the spacecraft before incorporation of incentive payments or penalties.

them in constant dollars. Here we will compare programs by expressing each incentive as a percentage of the maximum possible price that might be paid for that satellite.

The ability of incentive payments to influence the total price paid for the different satellites is shown in Table A.8. This table again shows the characteristics of the performance incentives paid on the first spacecraft of each series. The payments are all expressed as percent of the maximum price that could be paid, including both delivery price and all earned incentives, if the spacecraft operated successfully for its entire design lifetime. The table illustrates the relation of performance and price by showing the percent of maximum price that will be paid if the satellite operates successfully (1) throughout its full design life, (2) throughout the first half of the design life and then fails, or (3) not at all. Table A.8 also shows the relative price the supplier receives in the event of a booster failure that eliminates his chances of earning performance payments.

Table A.7

THE VALUE OF INTELSAT PERFORMANCE INCENTIVES
(Millions of then-year dollars)

Program	First Launch	Delivery Price	Maximum Incentives Positive	Maximum Incentives Negative	Non-orbit Payment
ISAT-II	1966	2.7	1.9		0.5
ISAT-III	1968	5.9	2.7		1.3
ISAT-IV	1971	14.1	4.8		3.2
ISAT-IVA	1975	19.9	4.4		4.2
ISAT-V	1980	30.8	8.4		6.3
ISAT-VI		104.5	22.3	14.0	12.6

SOURCE: Analysis of INTELSAT contracts.
NOTE: Entries apply to first satellite in each series.

Table A.8

PERCENT OF MAXIMUM PRICE PAID UNDER
ALTERNATIVE PERFORMANCE SCENARIOS

Program	Design Life (yr)	Performance Scenarios: Design Life (%)	Half Life (%)	Initial Failure (%)	Launch Failure (%)
ISAT-II	4	100	79	57	68
ISAT-III	6	100	85	66	82
ISAT-IV	7	100	95	74	91
ISAT-IVA	7	100	96	83	100
ISAT-V/VA	7	100	88	75	94
ISAT-VI	10	100	88	72	92

SOURCE: Analysis of INTELSAT contracts.
NOTE: Entries apply to first satellite in each series.

Table A.8 highlights several aspects of the incentives. First, it demonstrates that incentives do affect price. In the least case, for ISAT-IVA, the on-orbit incentive can make a difference of 17 percent in the full price received by the spacecraft supplier. Second, the table indicates an interesting change in the relationship between incentive payment and price over time. The price of an ISAT-II that failed immediately was 43 percent less that the full price of one that operated satisfactorily throughout its full four-year design life—the most influence or leverage of performance on price among the contracts. The difference between minimum and maximum price fell to 34 percent for ISAT-III and then to 26 and 17 percent for ISAT-IV and ISAT-IVA, respectively. But then the trend reversed, and the percentage increased to 25 for ISAT-V and to 28 for ISAT-VI.

Since incentives are both a measure of risk and a method of transferring risk between buyer and developer, it seems logical to assume that the trends in incentive payments shown in Table A.8 are somehow related to changes in risk between the programs. It further seems reasonable to assume that overall risk was steadily decreasing over these programs as both developer and buyer gained experience, at least through the ISAT-I, ISAT-II, ISAT-IV, and ISAT-IVA series, which were all produced by Hughes. That trend should have culminated in ISAT-IVA, which was a modest refinement and extension of the ISAT-IV design and may represent a minimum level of technical risk for the systems considered here.

This interpretation is consistent with the trends shown in Table A.8. The non-orbit compensation steadily increases from ISAT-II through ISAT-IVA, presumably reflecting the notion that the probability of extensive service life (and corresponding incentive payments) is increasing from one program to the next. Furthermore, the rewards for full service life are larger in the early programs. However, these trends reverse after ISAT-IVA, suggesting that the most recent programs may have somewhat more challenging design objectives and hence carry a higher risk of failure.

One further general aspect of these performance payments is worth examining. INTELSAT officials contend that under most of their contracts the spacecraft supplier loses money if his spacecraft do not perform well on orbit. Since we saw in Table A.8 that spacecraft prices could have varied historically by as much as 34 percent, and more recently by 25 to 28 percent depending on performance, the INTELSAT beliefs are probably valid; it would be unrealistic for a contractor to assume he would achieve these levels of profit.

We now use the contracts and an INTELSAT data series to estimate the actual incentive payments received by the spacecraft suppliers. The ISAT-Vs have only a limited on-orbit history and none of the ISAT-VIs have been delivered so both of these newer systems will be excluded from this discussion.

Since at least 1969, INTELSAT has published a series of reports on the monthly technical status of INTELSAT satellites in orbit (On-orbit Status Reports). Beginning in 1974, these reports indicate the satellites that are entitled to full, to partial, or to zero incentive payments for the period. For earlier years we estimated incentive payments from the technical details on the individual satellites.

Table A.9 summarizes the information from those reports, the INTELSAT contracts, and the TRW Space Log. Background information may be found in Tables C.8 and C.9.

We infer that ISAT-I earned full performance incentives. We have no contract for ISAT-I and the On-orbit Status Reports cover little of its period of operation. However, the INTELSAT fact sheet indicates that the maximum incentives for this system amounted to \$3.0 million and associates that incentive with just a single satellite. Later Status Reports indicate

Table A.9

ESTIMATED ORBITAL INCENTIVES EARNED BY INTELSAT SATELLITES
(Millions of then-year dollars)

Spacecraft	Period of Operation	Maximum Incentive Years	Maximum Incentive Dollars	Estimated Incentive Dollars	Estimated Incentive % of Max.
ISAT-I					
F-1	4/65 - 1/69	ni	3.00	3.00	100
F-2	wnl	ni	ni	ni	ni
ISAT-II					
F-1	amf	4	1.92	0	0
F-2	1/67 - 4/69	4	1.92	1.04	54
F-3	3/67 - 1/70	4	1.97	1.36	69
F-4	3/67 - 2/69	4	1.97	0.74	38
F-5	wnl	4	1.97	0.48	24
ISAT-III					
F-1	lvf	6	2.70	1.25	46
F-2	12/68 - 3/70	6	2.70	1.29	48
F-3	2/69 - 9/72	6	2.70	1.97	73
F-4	5/69 - 7/72	6	2.70	1.85	69
F-5	lvf	0	0.00	na	na
F-6	1/70 - 5/71	6	1.70	0.33	19
F-7	4/70 - 1/72	0	0.00	na	na
F-8	amf	0	0.00	na	na
ISAT-IV					
F-1	5/75 - 11/82	7	4.82	4.82	100
F-2	1/71 - 11/73	7	4.82	2.26	47
F-3	12/71 - 1/79	7	4.82	4.82	100
F-4	1/72 - 12/74	7	4.82	4.82	100
F-5	6/72 - 4/80	7	3.26	3.26	100
F-6	lvf	7	3.26	2.75	84
F-7	8/73 - pres	7	3.26	3.24	99
F-8	11/74 - pres	7	3.26	3.22	99
ISAT-IVA					
F-1	9/75 - pres	7	4.16	4.16	100
F-2	1/76 - pres	7	4.20	4.20	100
F-3	1/78 - pres	7	4.20	4.20	100
F-4	5/77 - pres	7	2.20	2.20	100
F-5	lvf	7	2.20	2.20	100
F-6	3/78 - pres	7	2.20	2.20	100

SOURCE: Table A.1, contracts for INTELSAT spacecraft, and INTELSAT On-orbit Status Reports, January 1969 through December 1982.

NOTE: "ni" indicates we have no information on an item; "wnl" indicates a spacecraft was not launched; "na" stands for an item that is not applicable; "amf" stands for apogee motor failure; "lvf" stands for launch vehicle failure; and "pres" indicates the present time or at least as of June 1983, the date of the last INTELSAT On-orbit Status Report at our disposal.

that this satellite was still operating satisfactorily some four years after launch, so we will assume that its on-orbit performance was completely, or at least mostly, satisfactory.[3]

ISAT-II apparently did not fare so well. F-1 suffered apogee motor failure and probably earned no incentives. F-2, F-3, and F-4 each operated for a number of years. F-3 was generally satisfactory, but F-2 and F-4 had recurring control problems. These three satellites as a group probably earned about half of their possible incentives. F-5 was never launched and should have received an in-lieu-of-immediate-launch payment of $480,000, which for that system amounted to about one-fourth of the full incentives.

ISAT-III was INTELSAT's first spacecraft with a mechanically despun antenna, which apparently was the source of most of the problems associated with these spacecraft. Despite these problems, however, and despite two launch failures and one apogee motor failure, enough of the satellites were procured and put into service to satisfactorily meet all of INTELSAT's communication requirements. We estimate that as a group they earned nearly 55 percent of their possible incentives.

The ISAT-IVs were more successful in earning on-orbit performance incentives. Returning to the earlier custom, all eight satellites in this group were eligible for incentives, although the maximum possible earning for the four in the second buy was about a third less than the possible earning for those in the original buy. We estimate that at least four of the ISAT-IVs earned maximum incentives and that two more came quite close. One of the other spacecraft did not reach the proper orbit because of launch vehicle failure and should have been awarded the default fee of $2.75 million, which was nearly 85 percent of the maximum fees. The other satellite had a number of problems. One traveling-wave tube failed two years after launch and one receiver failed two years later.

The ISAT-IVAs were even more successful. We calculate that they have all earned 100 percent of their incentives, even F-5 which did not reach orbit. For the ISAT-IVAs, the payments for launch vehicle failure or for a delayed launch were equal to the maximum payments that could be paid for a successfully orbiting and performing satellite.

COMPARING PRICES FOR DIFFERENT INTELSAT SYSTEMS

We have discussed each INTELSAT system and looked at its price in then-year or contract-year prices. Now we will inflate all of those prices to 1983 dollars and compare the prices and the cost effectiveness of the different systems. Table A.10 reviews the historical perspective for the seven INTELSAT contracts, and then Table A.11 summarizes the prices in then-year dollars. Recall that for ISAT-I through ISAT-V we have INTELSAT's estimate of launch costs and for ISAT-I through ISAT-IVA we have estimated the performance incentives that were paid. For Table A.11 and the several that will follow we assume for comparison purposes that all of the ISAT-V and ISAT-VI spacecraft will earn full incentives; and we assume that launch costs for ISAT-VI will amount to $55 million in 1983 dollars for each spacecraft.[4]

[3]Our compilation of maximum incentives in Table A.9 differs somewhat from the maximum incentives that INTELSAT reports in its fact sheet (Table C.1).

Source	ISAT-I	-II	-III	-IV	-IVA
Fact sheet	3.0	5.5	8.7	32.3	19.1
Contract	3.0	9.8	12.5	32.3	19.2

[4]INTELSAT publication BG-55-36E W/6/83 (attachment 1), dated 16 June 1983, indicates that NASA offered to launch the first two ISAT-VIs for $134 million (exclusive of perigee stages, which are included in spacecraft contract)

To express system prices in 1983 dollars we first estimated the time phasing of the actual payments associated with each contract. To do this, we took the payment schedule from the contract, updated it according to the amendments, and determined the total payments that should have been made in each fiscal year covered.[5] From the information available to us we cannot tell if the payments were in fact made according to those schedules, but for purposes of this exercise we assume INTELSAT paid each amount 30 days after its indicated due date on the latest schedule in our possession. The payment schedule for ISAT-III was not available, so we estimated a time profile for it based on the profiles for ISAT-IV and ISAT-IVA. That procedure is documented below. We had even less information on ISAT-I, so we assumed it was paid for entirely in 1965, the year of launch.

Table A.10

DATES OF INTELSAT CONTRACTS AND MAJOR OPTIONS

Item	ISAT-I	-II	-III	-IV	-IVA	-V/VA	-VI
Contract date	4/64	11/65	5/66	10/68	5/73	9/76	4/82
Initial launch	1965	1966	1968	1971	1975	1980	1986
Spacecraft bought	2	5	6+1+1	4+4	3+3	7+1+1 +3+3	5
Date of buys			2/69 11/69	7/70	12/74	4/80 thru 5/82	

SOURCE: INTELSAT contracts and amendments.

Table A.11

PRICES OF INTELSAT PROGRAMS IN THEN-YEAR DOLLARS
(Millions)

Item	ISAT-I	-II	-III	-IV	-IVA	V/VA	-VI
Spacecraft	7	14	47	81	102	436	523
Incentives	3	4	7	29	19	139	112
Launch	4	18	42	144	144	695	382
Total	14	36	96	254	265	1270	1017

SOURCE: Tables A.1, A.3, and C.1.

in then-year dollars. If we assume the launches are both scheduled for 1986, the price translates to $106 million in 1983 dollars. Later launch costs must include perigree stages, priced at $2 million to $4 million each. *Aviation Week and Space Technology* reports that INTELSAT and Arianespace have agreed on a $52.6 million (1984 dollars) price for the launch of ISAT-VI F-3 (April 2, 1984, p. 20).

[5]We used U.S. government fiscal years since the payments would be escalated by Air Force-derived inflation factors.

Launch cost profiles were estimated by taking the reported amounts from Table A.1, dividing by the number of launches, and assuming the actual payment was made in full one month after each launch. We profiled the on-orbit performance incentives using information from INTELSAT's On-orbit Status Reports. Tables C.10, C.11 and C.12 show our fiscal year profiles for the spacecraft, launch, and performance incentive payments, respectively.[6]

Estimation of Payment Profile for ISAT-III

Because we had no payment schedule for ISAT-III, we estimated one based on information from ISAT-IV and ISAT-IVA. We first distributed the payments for these systems, and for the first and second buys of ISAT-IV and ISAT-IVA, into six-month periods beginning with the effective date of each contract. Table A.12 reports the percentage distribution of these payments.

We then used those profiles to estimate alternative payment profits for ISAT-III. Five profiles were estimated (see Table A.13). Estimate A is based on the average of the ISAT-IV and ISAT-IVA payment profiles. Estimate B uses separately computed profiles for first and second buys based on the disaggregate ISAT-IV and ISAT-IVA data. Since ISAT-III was composed of three buys, we used the follow-on profile twice. Estimate C assumes total payment was made when the contract was signed. Estimate D assumes full payment for each buy when

Table A.12

DISTRIBUTION OF SPACECRAFT PAYMENTS
AFTER SIGNING OF PURCHASE COMMITMENT
(Percent)

6-Month Period	Total Contract ISAT-IV	Total Contract ISAT-IVA	First Buys ISAT-IV	First Buys ISAT-IVA	Second Buys ISAT-IV	Second Buys ISAT-IVA
1	15	6	22	10	0	0
2	17	17	24	28	0	0
3	15	20	22	34	0	0
4	21	14	14	18	38	9
5	14	15	11	8	21	25
6	6	14	4	2	11	31
7	4	6	1	0	9	15
8	5	5	1	0	14	12
9	1	2	0	0	1	5
10	1	1	1	0	2	2
11	0	0	0	0	0	1
12	0	0	0	0	1	0
13	0	0	0	0	1	0
14	1	0	0	0	2	0
Total	100	100	100	100	100	100

SOURCE: Analysis of INTELSAT contracts and amendments.

[6]The entries for spacecraft payments in Table C.10 are net of the schedule penalties discussed previously for the ISAT-III and ISAT-V programs.

it was finalized. Estimate E assumes full payment on the date of first launch. We believe these alternatives fairly well suggest the uncertainty associated with this estimation exercise.

The 1983 prices of the escalated profiles are shown in Table A.14. We believe Estimate B most clearly approximates the probable profile and adopt that estimate for use here and in the text

INTELSAT Prices in 1983 Dollars

The time profiles of payments for all of the INTELSAT satellite systems were next transformed into 1983 dollars using escalation factors obtained from the Directorate of Cost Analysis of the U. S. Air Force's Space Division. The factors are shown in Table D.1 of App.

Table A.13

ALTERNATIVE PAYMENT PROFILES FOR ISAT-III
(Thousands of then-year dollars)

Fiscal Year	Estimate (Thousands of then-year dollars) A	B	C	D	E
1967	12951	14978	47095	35662	0
1968	16484	15691	0	0	0
1969	11539	4280	0	3933	0
1970	4710	356	0	7500	47095
1971	942	3044	0	0	0
1972	0	5031	0	0	0
1973	469	2916	0	0	0
1974	0	572	0	0	0
1975	0	116	0	0	0
1976	0	111	0	0	0
Total	47095	47095	47095	47095	47095

SOURCE: Application of profiles from Table A.12 and elsewhere to contract price of ISAT-III.

Table A.14

ESTIMATES OF ISAT-III PRICES

Estimate	1983 Dollars	Percent Difference from Estimate B
A	161.336	3
B	156.433	0
C	171.049	9
D	165.684	6
E	145.335	-7

SOURCE: Escalation of payments from Table A.13 using factors from Table D.1.

D. In that appendix we also show that our findings are little affected by the choice of escalation factors.

Table A.15 shows our estimates of INTELSAT system costs in 1983 dollars. With these estimates, it is now possible to compare the costs side by side, but remember that each system consisted of a different number of spacecraft and that the capacity of each succeeding system increased (usually substantially) over that of the prior system. The lower portion of Table A.15 shows the relative contributions to the total system cost provided by the spacecraft contract price, the launch price, and the estimated performance incentives. An interesting feature of these estimates is the large portion of the space segment price contributed by the launch costs. Launch costs seem to average nearly half of the total system price. The estimates for ISAT-I and ISAT-VI are both much less, but these are special cases. ISAT-I involved the purchase of two satellites but the launch of only one. If the second had been launched, the reported launch costs would probably have doubled, bringing them also up to about half of the total system price.

The low estimate of launch costs for ISAT-VI is apparently a result of its design and the contracting arrangement. The perigee propulsion unit as well as the apogee kick motor are being designed and integrated by the spacecraft supplier under the spacecraft contract. (The first two perigree stages are also being purchased under the spacecraft contract.) INTELSAT and Hughes feel this arrangement will lower the total system price of the ISAT-VI.

Table A.15

PRICES OF INTELSAT PROGRAMS IN CONSTANT DOLLARS

Item	ISAT-I	-II	-III	-IV	-IVA	V/VA	-VI
	In millions of 1983 dollars						
Spacecraft	25	48	156	243	211	579	556
Incentives	11	12	21	66	33	98	57
Launch	17	65	134	352	247	620	275
Total	53	125	311	[illegible]	491	1297	888
	As percent of total						
Spacecraft	47	38	50	37	43	45	63
Incentives	21	10	7	10	7	8	6
Launch	32	52	43	53	50	47	31
Total	100	100	100	100	100	100	100

SOURCE: Escalation of payments from Tables C.10, C.11, and C.12 using factors from Table D.1.

THE COMMUNICATIONS CAPACITY OF INTELSAT'S SATELLITES

Although the prices of INTELSAT satellites have increased steadily, even when expressed in common 1983 dollars, each satellite series has increased the communications capability of INTELSAT. We will briefly summarize the capabilities of the satellites, and then derive and compare "price per circuit" estimates to illustrate the improving cost effectiveness of the successive systems.[7]

ISAT-I

Early Bird, an active-repeater, spin-stabilized satellite built by the Hughes Aircraft Company, was the world's first commercial communication satellite. COMSAT purchased two Early Bird (or HS-303) satellites for INTELSAT in March 1964.[8] The satellites were delivered early in 1965 at a total price of $6.5 million. Early Bird 1 was launched on April 6, 1965, and declared operational two months later. ISAT-II was in production soon after and the need to launch the second Early Bird satellite never arose.

To maintain stabilization in orbit, the entire 85-lb, drum-shaped satellite was spun. This, however, resulted in much of the signal power from the satellite's antenna being radiated into space rather than focused on the earth. The designers compensated for this somewhat by "squinting" the antenna toward the north, as the primary function of the satellite was to serve the heavily trafficked North Atlantic area. Early Bird carried 240 simultaneous telephone calls or one television program but had no multi-user capability—only one pair of earth stations could operate with the satellite at any one time. Although its design life was only 18 months, the satellite operated until May 1970, some five years after its launch.

ISAT-II

ISAT-II, the Hughes 303-A sometimes referred to as Blue Bird, was initially launched to provide communications in support of NASA's Apollo program. The contract for ISAT-II was signed between COMSAT and Hughes on November 15, 1965. It called for (1) the design, fabrication, and assembly of one test model spacecraft from existing HS-303 components, and then (2) the design, development, fabrication, assembly, and test of four flight spacecraft in accordance with new specifications.

These satellites were similar in many ways to Early Bird but did incorporate some major advances. To provide worldwide communications, the antennas were no longer squinted; the ISAT-IIs transmitted a toroidal pattern covering the whole of the surface of the earth visible from their geostationary orbit, but they still radiated much of their power into space.

[7]Since the focus of this report is on communication satellites, we will briefly note the general characteristics of the associated ground stations. An operational INTELSAT satellite may communicate to over 100 fixed earth stations located in many different nations. These earth stations are generally owned and operated by the international telecommunications organizations of the nations in which they are located and fall within three types: Standard A, Standard B, and Standard C. Standard A stations operate in the 6/4-GHz range and have 30-meter, or larger, antennas. They are the most widely used earth stations. Standard B stations also operate at 6/4 GHz but have smaller 11-meter antennas that use satellite capacity less efficiently. Charges are typically about 50 percent higher for circuits routed through Standard B stations. The Standard B stations, however, are less expensive to construct and typically serve as entry stations until traffic growth warrants the larger investment of a Standard A station. Standard C stations operate at 14/11 GHz and have 14- to 19-meter antennas. All of the antennas used by INTELSAT earth stations incorporate parabolic dishes, a design that provides maximum efficiency for a given size.

[8]COMSAT provided the initiative in procuring ISAT-I and -II and in setting up trans-Atlantic international satellite service. COMSAT remained the official procuring agent for INTELSAT systems through ISAT-IVA and still provides contract support and laboratory services.

To maintain the 240 telephone conversation or one television program capacity of Early Bird, and now cover the entire earth rather than only a portion, these satellites had to transmit stronger signals. Communications bandwidth was increased to 125 MHz and used a single conversion transponder that included four 6-watt traveling-wave-tube amplifiers (TWTA) which could be operated in parallel. The new transponder design gave the satellite a multiple-user capability, enabling it to be fed by a large number of earth stations simultaneously. The Blue Birds obtained their communications capability using only one active (and one redundant) transponder in place of Early Bird's dual (but only 25 MHz each) independent design.

ISAT-III

The ISAT-III contract for spacecraft and related equipment was signed on May 7, 1966, between COMSAT and TRW, Inc. It called for the production of two engineering model spacecraft, one prototype, six flight spacecraft, and associated test equipment, ground station telemetry and control equipment, apogee motors, spares, and test plans.

The ISAT-IIIs provided a dramatic increase in capacity over that of the earlier designs. Two 10-watt transponders, each with a bandwidth of 225 MHz, allowed a capacity of 1,500 circuits, or four TV channels, or combinations thereof.[9] INTELSAT satellites could now simultaneously transmit messages and television for the first time. ISAT-III also had an expanded multipoint communications capability that allowed for telephone, telegraph, television, high-speed data, and facsimile transmissions. Design life was increased to six years.

A major innovation introduced in ISAT-III was a mechanically despun antenna. A motor driving the antenna at the same speed but in the opposite direction to the spin of the satellite body allowed full transmission power to be focused on the earth. ISAT-IIIs were placed over all three major ocean areas—Atlantic, Pacific, and Indian—so that, in 1969, INTELSAT for the first time achieved full global coverage.

ISAT-IV

INTELSAT returned to the Hughes Aircraft Company for the development and acquisition of ISAT-IV. The contract was signed on October 18, 1968. The ISAT-IVs once again provided a large increase in capacity—to an average of 3,750 simultaneous telephone circuits and two television channels. This was achieved through the use of 12 communications transponders (each with a 36 MHz bandwidth) and a new configuration of antennas. Each satellite had one spot beam parabolic reflector and four global horns (two for transmit and two for receive). The spot beam antenna was steerable on commands from the ground and could transmit high-energy beams toward small areas on the earth.

These satellites again had multiple access and simultaneous transmission capabilities, and they added the capacity for digital communications. Design life was increased to seven years. The ISAT-IVs were spin-stabilized with the communication subsystem placed on the despun platform along with the antennas.

ISAT-IVA

The follow-on contract for ISAT-IVA spacecraft and equipment was the first contract with INTELSAT as the direct purchaser, COMSAT remaining as "manager." It was signed on

[9] ISAT-III was the last INTELSAT satellite to have no redundant transponders or TWTs.

April 27, 1973, with Hughes, making it the fourth contract with Hughes out of the first five INTELSAT contracts.

The ISAT-IVAs were derivations of the ISAT-IV models: the satellite bus and much of the communication subsystem remained unchanged, but alterations in the antennas and in the number of transponders allowed the communications capacity to increase to 6,000 circuits, plus two TV channels.

ISAT-V

INTELSAT contracted for the ISAT-V on September 21, 1976, with the Aeronutronic Ford Corporation, acting on behalf of its Western Development Laboratories Division. The first amendment to the contract officially changed the supplier's name to Ford Aerospace and Communications Corporation; the ninth amendment removed all mention of COMSAT, which at that time "ceased to act as Management Services Contractor for INTELSAT under this contract."

ISAT-V is the first INTELSAT satellite to use three-axis stabilization.[10] The main structure is in the form of a box upon which is mounted an antenna tower and from which extend "wings" of solar cells. This is also the first INTELSAT satellite to employ 14/11 GHz as well as 6/4 GHz communications. ISAT-V more than doubled the ISAT-IVA satellite's capacity—to 12,000 simultaneous telephone conversations plus two television channels.

Later-model ISAT-V satellites also carry a maritime communication package (MCP) to provide communications services to ships of member nations of the International Maritime Satellite Organization (INMARSAT). One transponder operating at 1.6/1.5 GHz provides ship-to-satellite and satellite-to-ship services and one 6/4 GHz transponder provides shore-to-satellite and satellite-to-shore communications. The forward link (shore-to-ship) carries 30 voice links or the equivalent in time-division-multiplex. The return link carries 30 to 35 voice links, plus search-and-rescue and data.

ISAT-VA

Even before the ISAT-V series was launched, it was obvious that still more capacity would be required in the INTELSAT system by the mid-1980s. Planning for the ISAT-VA series was started by Ford in 1980 with the objective of having satellites available for launch in 1984. These new satellites retain many of the improvements introduced during the ISAT-V series, such as nickel-hydrogen batteries, along with modifications to improve their capacity—up to 15,000 two-way telephone conversations plus two TV channels. Design life remains at seven years.

ISAT-VI

Hughes is developing the ISAT-VI under a contract signed on April 7, 1982, for the development and production of five spacecraft, related equipment, and launch support services. INTELSAT reports that ISAT-VI "will have a capacity of about 40,000 telephone circuits. This capacity will be derived by reusing some frequency bands up to six times through spatial

[10] All of the earlier satellites were basically cylindrical drums clad with solar cells to provide the necessary electrical power.

and polarization separation, extensive use of digital transmission techniques allied with a satellite switching capability, and possible use of new frequency bands."[11]

ESTIMATING SYSTEM COST EFFECTIVENESS

Now that we have briefly summarized the capabilities of the satellites, we can derive and compare "price per circuit" estimates to illustrate the improving cost effectiveness of the systems.

To put the different INTELSAT systems on as comparable a basis as possible, we compute their cost per unit of communications capacity. This measure, shown in Table A.16, dramatically illustrates the large technological advances incorporated in these satellites.

To construct this table we combined information on the number of two-way voice circuits reported by INTELSAT for each system with our estimate of the number of months of on-orbit availability provided by that system. We have rather good estimates of actual availability for ISAT-I through ISAT-IVA. For those systems, on-orbit performance steadily increased, and both ISAT-IV and ISAT-IVA earned close to maximum performance incentives. Based on that experience we have assumed, for the purposes of this comparison, that ISAT-V and ISAT-VI will perform up to their full design specifications.

Table A.16 shows the great advances in communications and manufacturing technology of the successive systems. ISAT-III represented a 3- to 4-fold increase in cost effectiveness over -I and -II; it was the first large system-to-system advance. The ISAT-IV/IVA series then lowered the cost-per-circuit of ISAT-III by about a factor of 5. ISAT-V will probably triple the performance of ISAT-IVA after its on-orbit performance is fully recorded. And ISAT-VI, if it operates at all successfully on orbit, should at least double the performance of ISAT-VA.[12]

Table A.16

COMPARING INTELSAT SATELLITE PROGRAMS

Item	ISAT-I	-II	-III	-IV	-IVA	-V/A	-VI
Total price (millions of 1982 $)	53	125	311	661	491	1297	888
Satellites (number)	2	4	8	8	6	15	5
Av. price (millions $/sat)	27	31	39	83	82	86	178
Capacity (million circuit months)	0.01	0.02	0.20	2.0+	2.0+	16.6	24.0
Av. price ($/circuit month)	5000	6000	1500	<300	<250	78	37

SOURCE: Computations using information from Table C.13.

NOTE: Actual on-orbit capacity was estimated for ISAT-I through ISAT-IVA, design specifications and life used for ISAT-V and ISAT-VI.

[11] *INTELSAT Is*, p. 16.

[12] This prediction should hold even if there are several follow-on buys of ISAT-VIs. Historically the prices for the initial buy of spacecraft have been quite representative of prices for follow-on buys. For example, in the ISAT-V program the initial buy of 7 spacecraft, including development work, was priced at $177 million (then-year) dollars, or $25.3 million per spacecraft. F-8 was later purchased for $27 million; F-9 for $23 million; F-10/11/12 for about $33 million each; and F-13/14/15 for about $23 million each. F-10 thru F-15 will contain more 6/4 GHz band communications capability than the earlier models but will not have the 1.6/1.5-GHz Marine Communications Subsystem.

Appendix B

THE PRICE OF THE AIR FORCE'S DSCS SATELLITES

INTRODUCTION AND OBJECTIVES

The Defense Satellite Communications System (DSCS) is an evolutionary DoD system developed to provide 8/7 GHz satellite communication for secure voice and data transmissions. The DSCS supports the majority of U.S. government capabilities for worldwide military command, control, and crisis management; intelligence and early warning detection; treaty monitoring and surveillance information; and diplomatic traffic.

The command and control role requires more independence in station-keeping ability, resistance to jamming and electronic countermeasures, and protection from physical attack than is found in commercial satellites.

This appendix follows the lead of App. A by first discussing spacecraft prices, launch prices, and on-orbit performance payments separately. Then all prices are converted to 1983 dollars and, finally, summed to derive the total amounts paid for the DSCS space segments.

SPACECRAFT PRICES

Three generations of DSCS satellites are discussed in the text of this report. Each is discussed below.

IDCSP

The Initial Defense Communication Satellite Program (IDCSP)[1] satellites were placed in near-synchronous circular equitorial orbits during 1966–1968 to demonstrate the feasibility of a military satellite communication system. Philco produced over 30 of these satellites, 26 of which were eventually launched and provided service into 1973.

The contract for the acquisition has been archived and is not available for inspection. A Space Division historical publication, however, indicates that $30 million was allocated for this system, and that most of it was probably expended in 1966.[2]

DSCS-II

The DSCS-II program was started in 1969. Since 1971, a total of 15 DSCS-II satellites have been launched, with four failing to achieve orbit because of booster malfunctions. With the launch of a pair of DSCS-II satellites in November 1979, the DSCS program achieved its authorized six satellite orbital configuration. DSCS-II satellites are currently deployed over four geographical regions: the Indian Ocean, the Western Pacific Ocean, the Eastern Pacific Ocean, and the Atlantic Ocean.

[1]After the system was declared operational in 1968, its name was changed to the Initial Defense Satellite Communications System (IDSCS).

[2]*Space and Missile Systems Organization: A Chronology, 1954–1979*, Office of History, Space Division, (not dated) p. 147.

Two major contracts supported the DSCS-II acquisition: an initial contract for RDT&E effort and six flight spacecraft; and a replenishment contract that ultimately procured 10 more spacecraft. These will be discussed in turn.

The Initial DSCS-II Contract. Contract F04701-69-C-0091 was signed in February, 1969, to "Design, develop, fabricate, assemble, and test six flight quality communication satellites and their associated support equipment required to launch the satellites on T-IIIC boosters." The original target cost was only $33.9 million, however, and did not cover production of the six satellites. Target profit was $3.8 million or just over 11 percent of the target cost, and target price was $37.7 million. Ceiling price was $40.7 million or exactly 8 percent more than the target price. Almost immediately, however, the option was exercised to formally purchase the six spacecraft, adding $25.3 million to the target price, and increasing the contract total to $63 million. In computing the price change for this contract we use this full $63 million as the basic contract price. Details of these prices are shown in Table C.14.

Because the conformed copy, or current version, of the contract was not available, we had to look elsewhere for payment information. We found that the Air Force Plant Representative Office (AFPRO) at TRW, the spacecraft supplier, had copies of the invoices presented by TRW for payment under both this contract and the replenishment contract discussed below. The AFPRO also allowed us to examine forms indicating the portions of requests that were approved for payment by the Air Force Administrative Contracting Officer (ACO).

Table B.1 summarizes the AFPRO-approved requests for progress payments and liquidations by TRW under the initial DSCS-II contract, which was apparently overrun. A TRW letter dated October 31, 1978, states that the total of all contract costs TRW had incurred as of September 29, 1978, was $86.44 million, whereas the value of all contract liquidation events was only $75.70 million. The letter also indicates that all liquidation events had been completed, accepted, and invoiced.

Table B.1

REQUESTS FOR PAYMENT UNDER THE INITIAL DSCS-II CONTRACT

(Millions of then-year dollars)

	Approved Requests		
Fiscal Year	Progress Payments	Liquidations	Total
1969	2.70		2.70
1970	35.83	6.81	42.64
1971	13.64	4.16	17.80
1972	0.26	6.87	7.13
1973	2.48	0.23	2.71
1974	3.51	1.27	4.79
1975		[illegible]	[illegible]
1976	0.45	0.24	0.69
1977		0.03	0.03
1978		0.24	0.24
Totals	58.87	[illegible]	75.67

SOURCE: Information from the TRW AFPRO office.

The DSCS-II Replenishment Contract. We analyzed both the original version and the conformed version of the F04701-74-C-0450 contract. The conformed version shows the amounts actually paid, unless post-contract adjustments updated inflation allowances or other entries. Ignoring such considerations, we extracted information from the amended contract that appears to represent the full, current cost for all items acquired under this contract. Comparing these items and prices with those listed in the original contract provides detail on the item and price changes that took place over the duration of the contract. This information is presented in Table C.15.

The contract was signed in October 1974 for the production of six DSCS-II satellites and associated equipment and data. The contract had an 80/20 sharing formula (80 percent for the government and 20 percent for the contractor) rather than the 50/50 rate of the initial contract. When this contract was signed, target cost for the original items was $66.0 million, target profit was $7.26 million (11 percent), target price $73.26 million, and the ceiling price $82.5 million (12.6 percent above target price). As of mid 1983, the target cost for this contract was $182.3 million, target profit was $19.6 million (11 percent), target price $201.9 million, and the ceiling price $221.4 million (nearly 10 percent above target price).

The major change to the contract was the addition of four more spacecraft and associated items, increasing the total price by nearly $91 million. All in all, additions to the contract contributed about 64 percent of its total contract price; 53 percent was contributed by the additional buy of satellites.

The DSCS SPO was able to provide a printout of the complete, official accounting records for this contract. Generated by the Air Force's Acquisition Management Information System (AMIS), the printout showed all contract transactions through the end of the 1983 fiscal year. Table B.2 pulls together information on progress payments, liquidations, royalty payments (for the purchase of F-13 through F-16), and storage (for F-16 and, especially, F-15) using information from the AMIS, AFPRO, and SPO.

This contract is still active, although essentially all of the work has been completed. As of February 1984, flight satellite F-15 remains in storage with the contractor. In addition to storage charges, it will eventually incur retesting and shipment costs. The TRW Contract Funds Status Report for September 30, 1983, shows TRW had charged the Air Force a total (for both cost recovery and profit) as of that date of $193.74 million. This agrees very closely with the AMIS information, which shows government payments of $193.94 million through September 30.

The DSCS SPO reports that the contract target price as of September 30 was $202.97 million. Combining this information with the AMIS records indicates that expenditures as of that date were $9.03 million less than the contract price. The SPO and the contractor agree that the contract is underrunning by about $5 million. Because any underrun will be shared in the ratio 80/20 by the government and TRW, it appears that the government's remaining payments should be about $5 million [$9.03 − 5.00) + (0.2 × 5.00) = $5.03].

Summary of DSCS-II Price Information. The contracts originally summed to $111 million. Additional items, mainly the purchase of more spacecraft, were priced at nearly $167 million, raising the current price to nearly $278 million. Table B.3 summarizes the information on prices in the DSCS-II contracts.

Table B.2

COMBINED INFORMATION ON PAYMENTS UNDER THE DSCS-II REPLENISHMENT CONTRACT

(Millions of then-year dollars)

Fiscal Year	Progress Payments	Royalty	Storage	Liquidations	Total Requests
1975	7.76			0.00	7.76
1976	33.14			12.36	45.50
1977	18.51			19.83	38.34
1978	25.23	0.02		9.74	34.99
1979	13.11			3.90	17.01
1980	7.43		0.13	9.85	17.41
1981	3.90		7.25	-1.23	9.92
1982	0.87		3.84	2.53	7.24
1983	7.19		5.50	3.09	15.78
Total	117.14	0.02	16.72	60.07	193.95
Remaining to be paid					5.03
Full price					198.98

SOURCE: Synthesis of information received from the AMIS system, DSCS AFPRO and SPO, and Commercial Services Division of AF Space Division.

NOTE: Entries may not sum to total due to rounding. Storage charges will need to be paid until F-15 is delivered for launch. Current charge rate is $458,531 per month. Liability for performance incentives extend potentially through fiscal 1988 or later, depending on when F-15 is eventually launched.

DSCS-III

The Department of Defense approved full-scale development of DSCS-III in January 1977. Shortly thereafter, General Electric (GE) was awarded a $76.6 million FPI contract to complete the satellite design; to develop, test, and support the launch of two demonstration flight satellites; to develop a refurbishable qualification model satellite; and to conduct and support on-orbit tests and evaluations. An Air Force Satellite Communications (AFSATCOM) System single-channel transponder was later added to the DSCS-III design.

We have examined the major contracts with the DSCS-III spacecraft supplier: a development contract valued at $174 million; a contract for the refurbishment of the development satellite, valued at $48 million; and the procurement contract, valued at $337 million.

The DSCS-III Development Contract. Development contract F04701-77-C-0036 for spacecraft and related equipment was effective February 1, 1977, between GE and the Air Force. At the beginning of this contract, the target cost for the original items was $73.5 million, target profit was $3.1 million (only 4 percent), target price $76.6 million, and the ceiling price $91.2 million (19 percent above target price). The sharing rate was set at 80/20. The contract has been changed many times since then, with many of the changes affecting price. In all, the changes have added $97 million to the contract, bringing the August 1983 price up to

Table B.3

SUMMARY OF PRICES IN THE DSCS-II CONTRACTS

(Millions of then-year dollars)

Item	Initial Contract	Replenishment Contract	Total
Original contract	63.0	73.3	111.0
Additional spacecraft		90.7	116.0
Contract growth	15.7	34.9	50.6
Current contract	78.7	198.9	277.6
Categories of growth			
Storage of F-15 and F-16		16.3	16.3
TWTA work and mods		7.7	7.7
Launch operations		1.9	1.9
Price increases	6.3[a]		6.3
Miscellaneous	9.4	9.0	18.4

SOURCE: DSCS-III contracts, payment records, and AMIS printout.

[a]Price increases computed as the difference between contract target and ceiling prices and estimated by assuming final percentage was the same as that specified in the beginning contract.

just over $174 million. Nearly two-thirds of the total dollar change is associated with the items that were called for in the original contract. Table C.16 summarizes the price information for this contract.

The DSCS-III Refurbishment Contract. Contract F04701-80-C-0058, calling for advance buy of long-lead-time parts for the refurbishment of the qualification satellite, was signed with GE on June 27, 1980. After about a year, it was amended to include effort to bring the spacecraft to full flight configuration. A number of smaller changes, mostly related to jammer locator electronics, were made to this contract prior to December 17, 1983, when it was amended to reconfigure the satellite from a Titan to a shuttle launch capability.

The replenishment contract has a target price of $66.3 million (as of September 30, 1983), allowing a target profit of $7.1 million on target costs of $59.2 million, a profit rate of 12 percent. Ceiling price is $71.6 million, some 11 percent above target price. Table C.17 details these prices.

The DSCS-III Production Contract. Production contract F04701-81-C-0004 for spacecraft and related equipment was effective October 12, 1982, between GE and the Air Force. It was signed for $46 million and is still active. The contract is basically FPI, but one item dealing with launch vehicle integration has been set up as cost-plus-fixed-fee. Target cost for the FPI items is $279.7 million (as of September 1983), target profit is $30.7 million (slightly less than 11 percent), target price $310.4 million, and the ceiling price $335.7 million (slightly more than 8 percent above target price). Estimated cost of the CPFF item is $23.6 million and the fixed fee is $1.8 million (nearly 8 percent). The total price is thus up to $336 million. Table C.18 contains the details.

Summary of DSCS-III Price Information. Table B.4 consolidates the DSCS-III price information. The current contracts total $569 million, although the sum of the initial versions was only $136 million. Most of the increase is attributable to the refurbishment of the development spacecraft and the purchase of four flight spacecraft. Over $90 million of the increase, however, resulted from changes and additions to the development contract.

The DSCS SPO helped us classify the modifications to the development contract. The largest identifiable item is the price increases on the space segment items (represented in the contract by a shift from target price to ceiling price for Items 1 and 2). This increase totals $21.9 million, or about 22 percent of the total development price change. Work to allow the spacecraft to be launched from the space shuttle, the addition and integration of the AFSATCOM single-channel transponder, and reworking and improving the high-power amplifiers account for most of the remaining increases.

Summary of Spacecraft Prices

Information concerning the two DSCS satellite communication systems in Tables B.3 and B.4. These tables show spacecraft prices, including all contractual payments from the government to the spacecraft supplier covering delivered spacecraft, storage costs, and other deliverable items, but excluding all on-orbit performance incentives and penalties. The tables indicate that the contract changes affecting the price of the DSCS systems are similar to those presented earlier for the INTELSAT systems. Nearly all of the price change associated with

Table B.4

SUMMARY OF THE THREE DSCS-III CONTRACTS
(Millions of then-year dollars)

Item	Development	Refurbish	Production	Total
Original contract	77	13	46	136
Additional spacecraft		31	251	282
Other change	98	22	39	159
Net	[illegible]	[illegible]	[illegible]	[illegible]
Categories of change				
Launch vehicle integration	12	18	26	56
Price increases	22			22
AFSATCOM				
SHF downlink	9			9
One-channel transponder	7			7
Amplifiers				
TWTA work & mods	9			9
10-W solid-state amplifier dev.	3			3
Storage and retest	7			7
Batson II integration	7			7
STS avionics mods	3			3
Gimbal dish antenna work	2			2
Miscellaneous	17	4	13	34

NOTE: Entries may not sum to total due to rounding.

these contracts is attributable to the purchase of additional items, usually more spacecraft. However, the DSCS systems generally did have more modifications and additions than did the INTELSAT systems, and there were more explicit price increases associated with the DSCS contracts.

LAUNCH PRICES

We obtained launch price information from the DSCS SPO at AF Space Division. The SPO reports having spent $272.6 million on launch vehicles for the DSCS-II and -III programs to date.[3] This amount purchased boosters, upper stages, and propellants for the launch of 16 DSCS-II satellites and two DSCS-III satellites. The DSCS satellites are all launched two at a time, so this purchase was to support nine separate launches. As of June 1984, 15 DSCS-IIs and one DSCS-III had been launched.

The DSCS-IIs were launched on Titan 3-Ds and a Transstage (upper stage), except for the final two, one of which was paired with a DSCS-III on a Titan 34-D and an inertial upper stage (IUS) booster in October 1982. The remaining DSCS-II is scheduled to be paired with another DSCS-III on a future launch.

The DSCS SPO is responsible for most of the vehicle costs for these launches, but with several major exceptions: first, IUS costs are not charged to the DSCS program but are funded completely through the IUS SPO;[4] second, launch support services are not charged against the DSCS SPO.[5]

Consequently, to estimate the price charged to the DSCS program for the launch of DSCS-II satellites we need only remove the cost of one booster from the $272.6 million reported above. The DSCS SPO indicated that one of the T-34-Ds procured in 1977 cost about $40.3 million (in 1977 dollars). Removing it from the total amount paid by the DSCS SPO leaves about $232 million actually paid for the launch of the DSCS-II satellites, or about $29 million per launch (of two satellites) in some type of then-year dollars.

We distribute these launch costs over time in the same manner we distributed the INTELSAT launch costs, assuming that one-eighth of the total was incurred for each launch and paid during the month following the launch. Note that the lump-sum information we have on DSCS-II launch prices is roughly similar to the level of detail we have on INTELSAT launch prices, but also note that the quality of the data is quite different. Launch prices paid by INTELSAT include charges for hardware (including all upper stages), launch operations, flight services, and management reserve, whereas the prices charged the DSCS program office are only for some of the hardware.[6]

The DSCS-II computations also yield costs for the first two DSCS-III spacecraft since each of these is paired for launch with a DSCS-II. We assume the other DSCS-III satellites will be launched in pairs using the STS/IUS. A 1985 launch, according to the current NASA price schedule, should cost about $48.8 million (then-year dollars) for the shuttle plus perhaps

[3]The IDCSP satellites were launched on Titan-IIIC's procured with Research and Development funds. The IDCSP program incurred no launch costs, and current sources give no estimates.

[4]Shuttle costs are handled in the same way through the Space Transportation System (STS) SPO, so if a DSCS is ever launched on a shuttle-IUS combination, few, if any, of the launch costs will be charged to the DSCS SPO.

[5]In fact, launch operation costs at Kennedy Space Center are not directly charged to the Air Force at all but are exchanged for costs incurred at Vandenberg by the Air Force in support of NASA payloads.

[6]The hardware prices charged the Department of Defense and commercial customers even differ. For example, shuttle prices charged commercial customers include the full incremental cost of the shuttle, whereas those charged the Air Force exclude propellants, ground-support equipment, and other consumables (which are bartered against similar charges incurred by the Air Force for NASA launches).

$50 million for the IUS.[7] Later launches are assumed to be priced at $100 million (1986 dollars) for the shuttle. Only seven DSCS-III spacecraft have been ordered thus far, but we price the final single spacecraft launch at 50 percent of the cost of a double launch because it will probably be paired with a spacecraft from a follow-on buy. IUS costs are very uncertain at this time but will probably not be less than $50 million or more per flight, and could be substantially more. For lack of a better estimate at this time, we assume the IUS costs after 1985 will be priced at $60 million each. Our complete estimated price profile for DSCS launches is shown in Table C.20.

INCENTIVES IN THE DSCS CONTRACTS

The DSCS-II and -III contracts contain provisions for on-orbit performance incentives and sometimes provisions for cost and schedule incentives. The current contracts (for DSCS-III refurbishment and production) also provide for an "award fee" if the contractor performs better than satisfactorily. The cost incentives affect the relationship of target and ceiling prices and were discussed earlier in this appendix. Here we discuss the schedule incentives, the performance incentives, and the award fee.

Schedule Incentives

Schedule incentives were applied to both of the DSCS-II contracts. The initial contract contained penalties for late delivery of (1) certain subsystem specifications, (2) the satellite qualification procedure, and (3) the two flight spacecraft. The penalties could amount to as much as $2,280,000. The follow-on contract, in contrast, offered bonuses for early delivery of the first two spacecraft, bonuses that could total $750,000. Table B.5 shows some of the detail associated with these provisions.

Table B.6 expresses the incentives as percentages of the spacecraft delivery prices.[8] Note that these penalties are much smaller than those associated with the INTELSAT contracts. INTELSAT usually associated schedule penalties with the first several spacecraft procured under each of its contracts, but more recently (e.g., ISAT-V and ISAT-VI) has set penalties for the late delivery of each spacecraft in multi-unit buys. These penalties have averaged about 5 percent of the spacecraft price. The DSCS-II incentives were small in comparison, and the DSCS-III contracts do not contain any schedule incentives.

On-orbit Performance Incentives

Both the DSCS-II and DSCS-III contracts specify performance incentives for the flight spacecraft, but the details differ greatly. The incentives are similar to the ones found in the INTELSAT contracts in that they are contingent on successful operation of the

The current tariff sets the price of a dedicated shuttle launch at $18.27 million 1975 dollars plus $4.30 million then-year dollars and is valid for fiscal years 1983, 1984 and 1985. This translates to $48.8 million then-year dollars for a 1985 launch. A new tariff sets the price for fiscal year 1986 and beyond at $38 million 1975 dollars, which translates to $100 million in 1986 dollars.

[8]In constructing Table B.6, we assumed that the original portion of the initial contract covered all development activities and represented the "price" of the specifications and procedures named in the table. We estimated the unit price of F-1 and F-2 by spreading the total contract growth of that contract evenly over the six spacecraft specified in the major amendment; and we estimated the price of F-7 and F-8 by spreading the current amount of the replenishment contract evenly over the eight spacecraft procured thereunder.

Table B.5

SCHEDULE INCENTIVES IN THE DSCS-II CONTRACTS

	Bonus		Penalty	
Item	Per Day	Max. Days	Per Day	Max. Days
Subsystem specifications			$285,000	1
Satellite qualification procedures			285,000	1
F-1 and F-2 delivery[a]			9,490	60
			26,019	30
F-7 and F-8 delivery[a]	$500,000	1		
	8,333	6		
	7,547	52		
	7,538	1		

SOURCE: DSCS-II contracts.

[a]Spacecraft bonus and penalty apply to the joint delivery of the two items.

Table B.6

DSCS-II SCHEDULE INCENTIVES AS PERCENT OF SPACECRAFT PRICE

Item	Contract Price	Maximum Incentive as Percent of Price: Bonus	Maximum Incentive as Percent of Price: Penalty
Specifications and procedures	29.7		1.92
F-1 and F-2 delivery	41.6		4.11
F-7 and F-8 delivery	201.9	0.37	

SOURCE: Tables B.5, C.14, and C.15.

communication mission of the satellites and are designed to encourage development and manufacturing practices that increase the probability that the satellites will operate successfully throughout their designed life.

DSCS incentive payments are both positive (giving the contractor bonus money for each period that the satellite operates successfully up to its designed lifetime) and negative (the contractor pays the Air Force a penalty for each period the satellite fails to operate successfully).

Several of the more important characteristics of the DSCS incentive provisions are shown in Table B.7. Two major differences between the DSCS incentives and the earlier INTELSAT incentives are quickly apparent: all of the DSCS contracts contain provisions for negative incentives, but only one makes a payment in the event of booster failure. The earlier contracts contained provisions for positive as well as negative incentives. However, current contracts for DSCS-III satellites provide only for penalties if the satellites perform less than satisfactorily. Details on the dollar values of these incentives are summarized in Table B.8.

The ability of incentive payments to influence the total price paid for the different DSCS satellites is shown in Table B.9. The table shows the characteristics of the performance

Table B.7

PERFORMANCE INCENTIVE SCHEDULES FOR DSCS SPACECRAFT

System	Length of Performance Period: Initial	Total	Payment Schedule
DSCS-II			
F-1/F-4	60 days	5 years	Payments computed bimonthly[a]
F-7/F-16	60 days	5 years	Payments computed bimonthly[a]
DSCS-III			
A-1/A-2	60 days	10 years	Payments computed bimonthly[a]
A-3	60 days	7 years	Penalties only
B-4/B-7	1 year	4 years	Penalties only

SOURCE: DSCS contracts and amendments.

[a]Payments are made semi-annually.

Table B.8

THE VALUE OF DSCS PERFORMANCE INCENTIVES
(Millions of then-year dollars)

Program	First Launch	Delivery Price	Maximum Incentives: Positive	Maximum Incentives: Negative	Non-orbit Payment
DSCS-II					
Initial	1971	13.1	1.42	1.71	
Replenishment	1977	25.2	1.65	1.10	(a)
DSCS-III					
Development	1982	87.5	15.00	5.00	0.1
Refurbishment		71.6		1.69	
Production		84.3		5.00	

SOURCE: Analysis of DSCS contracts.

NOTE: Entries apply to first satellite in each series. Delivery price is computed as the total contract price divided by the number of spacecraft procured.

[a]If a satellite is not successfully injected into orbit, the incentives that that satellite could have accrued will be transfered to a successfully operating satellite.

incentives paid on the first spacecraft of each series. The payments are all expressed as a percent of the maximum price that could be paid, including both delivery price and all earned incentives, if the spacecraft operated successfully for its entire designed lifetime.

Table B.9 shows that on-orbit incentives have been important in determining the full price the supplier receives for his satellites, but less so now than previously. This is in sharp contrast with the INTELSAT situation where the importance of the incentives has remained relatively constant at about 25 to 30 percent of the maximum price.

Table B.9

PERCENT OF MAXIMUM DSCS PRICE PAID UNDER ALTERNATIVE PERFORMANCE SCENARIOS

Program	Design Life (yr)	Performance Scenarios: Design Life (%)	Half Life (%)	Initial Failure (%)	Launch Failure (%)
DSCS-II					
Initial	5	100	85	59	81
Replenishment	5	100	93	83	(a)
DSCS-III					
Development	10	100	94	83	91
Refurbishment	7	100	99	97	100
Production	10	100	100	93	100

SOURCE: Analysis of DSCS contracts.

NOTE: Entries apply to first satellite in each series.

[a]Indicates that on-orbit incentives are added to future satellites.

The tendency of the DSCS contracts to deemphasize performance incentives culminates in the most recent DSCS-III contracts. These contracts allow for the maximum price to be paid if the satellite performs satisfactorily for the first four of its 10-year design life, or in the event of booster failure. If the satellite fails to perform at all, the supplier still receives nearly the maximum amount. It is clear that in these contracts the Air Force has changed its emphasis from performance incentives to award fees.

Before looking at the award fees, however, one further analysis of the performance incentive data is interesting. The Air Force, unlike INTELSAT and other commercial buyers, uses FPI contracts and attempts to monitor the cost performance of its suppliers. All of the DSCS contracts are written so that the target price corresponds to the supplier's target cost (which the Air Force accepts as a reasonable estimate of the supplier's probable costs) plus a profit margin of about 11 percent. This information allows us to examine the effect of spacecraft performance on the supplier's total "profit" from the satellite programs.

Table B.10 shows the findings of this procedure. Its entries represent the percentage by which the total price received by the supplier in each case exceeded target cost. All but one of the entries in the table are positive, meaning that in almost all cases the DSCS contracts specify prices that are above target costs. That is, except for the first contract, even if the satellites failed to operate at all, payments to the supplier still exceeded his target cost. The earlier contracts called for substantial profits if the satellites performed up to their design specifications. If the satellites operated for half their design life, the margins are still above the 11 percent usually thought of as the "normal" or target level, but not much above because portions of the payments will be received later and must be discounted to be strictly comparable with the delivery prices or target costs.

Table B.10

TOTAL TARGET PROFIT FOR DSCS SATELLITES

Program	Design Life (yr)	Total Target Profit as Percent of Target Cost Under Alternative Performance Scenarios: Design Life (%)	Half Life (%)	Initial Failure (%)	Launch Failure (%)
DSCS-II					
Initial	5	36	16	-19	11
Replenishment	5	24	15	3	(a)
DSCS-III					
Development	10	28	20	5	17
Refurbishment	7	12	11	9	12
Production	10	11	11	3	11

SOURCE: Analysis of DSCS contracts.

[a]Not applicable. In the event of booster failure the on-orbit incentives that could have been earned by these spacecraft were transferred to later spacecraft.

The trend in these contracts is clearly to reduce profit margins. The latest contract allows only for the target 11 percent margin even if the satellites perform perfectly. Note finally that most of these contracts specify that the supplier will receive only his target rate of return in the event of booster failure.

Performance Incentives Actually Earned

Information provided by the DSCS SPO allows us to factor actual payments for performance incentives into our price computations. Table B.11 displays this information in a manner comparable to that earlier used in the INTELSAT analysis. We have no information on the IDCSP satellites and only one DSCS-III has been launched, so the table reports only DSCS-II payments.

Incentives were originally attached to all of the satellites except F-5 and F-6. The early no-fault failure of F-1 resulted in the transfer of its incentives to F-5 and F-6; when those satellites were lost because of booster failure the incentives were not retransferred. F-9 and F-10 were also lost because of booster failure.

To date, 10 satellites have been successfully inserted into geosynchronous orbit, and only three of them have earned less-than-full incentives. Problems with the despun antenna on F-2 and F-3 caused both to lose their positive incentives; F-2 also incurred the maximum penalty. Failure of the narrow coverage downlink on F-7 in 1979 resulted in the loss of nearly half of its positive incentives.

The other seven satellites have each had minor problems but, thus far at least, all are earning full incentives. Positive incentives for F-11 and F-12 will run out in 1984; those for F-13 and F-14 continue into 1985. F-16 has operated successfully long enough to qualify for positive incentives that could continue into 1987.

Table B.11

ESTIMATED ORBITAL INCENTIVES EARNED BY DSCS SATELLITES
(Millions of then-year dollars)

Spacecraft	Period of Operation	Maximum Incentive		Estimated Incentive	
		Years	Dollars	Dollars	% of Max.
DSCS-II					
F-1	1971-71	5	(a)	0	0
F-2	1971-71	5	1.43	-1.43	-100
F-3	1973-75	5	1.43	0.04	3
F-4	1973-	5	1.43	1.43	100
F-5	lvf		(a)	0	0
F-6	lvf		(a)	0	0
F-7	1977-	5	1.65	0.89	54
F-8	1977-	5	1.65	1.65	100
F-9	lvf	5	(b)	0	0
F-10	lvf	5	(b)	0	0
F-11	1978-present	5	2.48	2.06	83[c]
F-12	1978-present	5	2.48	2.06	83[c]
F-13	1979-present	5	3.19	2.13	67[c]
F-14	1979-present	5	3.19	2.13	67[c]
F-15	wnl	5	2.37		
F-16	1982-present	5	2.37		(c)

SOURCE: Contracts for DSCS spacecraft, fact sheet from AF Space Division, and payment requests from TRW AFPRO.

NOTE: "ni" indicates we have no information on an item; "wnl" indicates a spacecraft was not launched; "lvf" stands for launch vehicle failure; and "present" indicates as of September 1983.

[a]When F-1 suffered no-fault failure its ($1.43 million) incentives were transferred to F-5 and F-6, but booster failure prevented their dispursement.

[b]Booster failure resulted in $3.3 million in possible incentives being spread over F-11, F-12, F-13, and F-14.

[c]These satellites are operating satisfactorily and may eventually earn 100 percent incentives.

The Award Fee

The DSCS-III refurbishment and production contracts have provisions for an "award fee" in addition to penalties for less-than-satisfactory performance by the on-orbit spacecraft. The DSCS SPO believes that an award fee, which can be earned as the contractor is developing, constructing, and testing the spacecraft, has the potential for more leverage on the contractor's actions than on-orbit bonuses, which are earned after the design is fixed and production is well along or even completed.

Award Fee is additive to the usual profit negotiated for a fixed price incentive-firm (FPIF) contract. Therefore, no Award Fee shall be awarded when performance is merely satisfactory and meets contract requirements. To merit Award Fee, the contractor must exceed normally expected performance for those areas to which the fee applies. Consequently, contractor's efforts rated below the Award Fee standard of "Good" will render the contractor ineligible to receive any Award Fee for the pertinent performance evaluation criteria.[9]

The award fee section of the production contract goes on to state that it "deals with areas under the control of management which are mostly susceptible to subjective evaluation" and "therefore, precise definition of all the factors possible for consideration is impossible." Nine areas, however, are listed as pertinent to the award-fee evaluation:

Program/subcontractor/vendor management
Cost management
System test and evaluation
Product assurance/system effectiveness
Systems engineering
Configuration management
Production management
Launch vehicle integration and launch support
TWTA subcontract management

The contractor can potentially earn \$1.85 million under this provision of the refurbishment contract and \$15 million under the production contract. Thus, for these contracts, the award fees are nearly as important as the on-orbit incentives.[10]

DSCS-II PRICES IN COMMON DOLLARS

We have looked at each of the DSCS system's price in then-year or contract-year prices. Now we inflate all of those prices to 1983 dollars and compare the prices and the cost effectiveness of the different systems. Table B.12 summarizes the prices discussed above. Recall that for DSCS-II we have the SPO's estimate of launch costs and of the actual performance incentives that have been paid. For Tables B.12 and B.13 we assume for comparison that the F-11 through F-16 DSCS-II satellites and all of the DSCS-III satellites will eventually earn full performance incentives and that the DSCS-III contractor will earn full future award fees.

To express the system prices in 1983 dollars, we used the time-profiles of requests for payments and assumed that the Air Force paid each amount 30 days after it was requested. Tables C.19, C.20, and C.21 document the time-profiles of payments we used for spacecraft, launches, and performance incentives, respectively. The spacecraft payments are net of cost and schedule penalties and include award fees.

We transformed these time-profiles into 1983 dollars using the AF Space Division's escalation factors.[11] The 1983 prices of the DSCS space systems are shown in Table B.13. The spacecraft prices include all contractual payments from the government to the spacecraft supplier covering delivered spacecraft, storage costs, and other deliverable items. They also take into account cost and schedule penalties and award fees. On-orbit incentives are shown separately.

[9]Attachment 10 to contract F04701-81-C-0004, *Award Fee Evaluation Plan, Defense Satellite Communications System III, Phase Three Space Segment*, November 1, 1982, p. 4.

[10]Table 14 in the text summarizes the importance of the DSCS and INTELSAT incentives.

[11]Appendix D shows the sensitivity of our findings to the escalation factors by performing the same analyses using alternative DoD and commercial factors.

Table B.12

PRICES OF DSCS SYSTEMS IN THEN-YEAR DOLLARS
(Millions)

	DSCS-II				DSCS-III			
Fiscal Year	IDCSP	Initial	Replacement	Total	Development	Refurbishment	Production	Total
Spacecraft	30	79	199	278	174	68	350	592
Incentives	ni	0	19	19	30	30		
Launch	ni	87	145	232	29	49	334	412
Total	(30)	166	363	529	233	117	684	1034

SOURCE: Previous tables and text discussion.
NOTE: Estimates include maximum incentives for current and future spacecraft.

In both INTELSAT and Air Force programs,launch cost is a large portion of the total space segment price. But note that the Air Force is not charged consistently for all launch-associated items, and hence the ratio of launch price to spacecraft price varies widely and is not directly comparable with INTELSAT launch costs.

COMMUNICATIONS FEATURES OF DSCS SATELLITES

The DSCS system is currently procuring and deploying its third generation of satellites. For comparison with INTELSAT systems, and to support Table 1 in the text, we will briefly describe the technical characteristics of each DSCS system.[12]

IDCSP

The Initial Defense Communications Satellite Program (IDCSP)[13] satellites were placed in near-synchronous circular equitorial orbits during 1966–1968 to demonstrate the feasibility of a military satellite communications system. These polyhedron-shaped satellites were solar-powered repeaters, weighing 97 lb each and measuring about 33 in. across.

The IDCSP satellites were designed for the Air Force by the Philco division of Ford Motor Co. They were launched seven at a time on a Titan III-C booster; the satellites were separated from their dispenser in pairs by compressed springs, so each had a slightly different velocity. At first somewhat bunched together, they spread out fairly evenly over several months. The design plan was that 14 of them, working perfectly and properly spaced, would provide near-global coverage 24 hours a day.

[12]This discussion of the DSCS system is based on Brown (1981), Martin (1979), Vreeburg (1974), Wall (1968), material contained in the DSCS II and III development and production contracts and discussions with personnel at the DSCS SPO and the Aerospace Corporation.

[13]After the system was declared operational in 1968, its name was changed to the Initial Defense Satellite Communications System (IDSCS).

Table B.13

PRICES OF DSCS SYSTEMS IN CONSTANT DOLLARS
(Millions of 1983 $)

	Prices by Program and Contract[a]							
		DSCS-II			DSCS-III			
Item	IDCSP	Initial	Replacement	Total	Development	Refurbish	Production	Total
Prices								
Spacecraft	115	231	307	538	212	68	319	599
Incentives	ni	-1	18	17	21			21
Launch	ni	208	200	408	28	42	261	331
Total program	(115)	438	525	963	261	110	580	951
Number of spacecraft	37	6	10	16	2	1	4	7
Unit price	3	73	53	60	131	110	145	136

SOURCE: Escalation of payments from Tables C.20, C.21, and C.22, using factors from Table D.1.

NOTE: Detail may not sum to total due to rounding. Spacecraft prices include net award, cost, and schedule incentive payments through fiscal year 1983, and all potential award fees for later years; on-orbit incentives are estimates of actual incentives through fiscal year 1983 and maximum incentives thereafter.

[a]The DSCS-II system was procured through an initial contract and a replacement contract. The DSCS-III system involves a development contract, a refurbishment contract (for the qualification satellite), and a production contract.

Philco produced over 30 of these satellites. Twenty-six of the flight satellites were eventually launched successfully and provided service into 1973.

DSCS-II

After the IDCSP program demonstrated that satellite communications could satisfy some military requirements, the Department of Defense decided to proceed with the development of more advanced satellites. The DSCS-II (or Phase II) satellites were quite different from the IDCSP models, having a command subsystem, attitude control and station-keeping ability, multiple communication channels with multiple access, and a small amount of hardening to protect them from nuclear attack.

Like the earlier INTELSAT spacecraft, the DSCS-II satellites have a dual-spin configuration. An outer section containing the cylindrical solar array and much of the structure is spun to stabilize the satellite. The inner section containing the communications equipment and antennas is isolated from the outer section by a motor and bearing assembly. The motor despins the inner section so that the antennas are always pointed at the earth. The satellite has two parabolic reflector antennas and two horn antennas.

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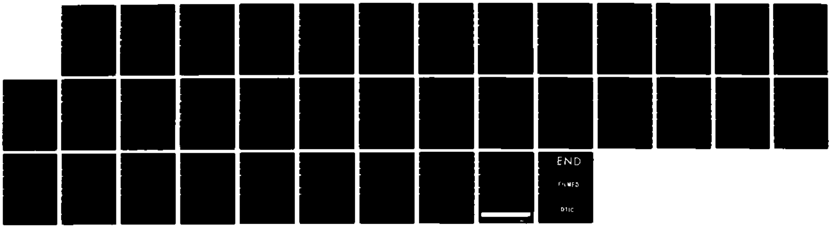

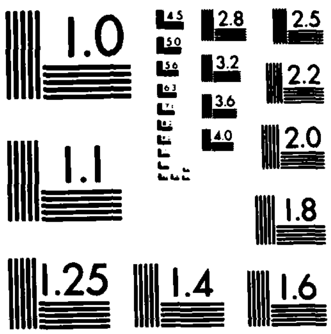

MICROCOPY RESOLUTION TEST CHART

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Unlike the more recent INTELSAT satellites, the DSCS-IIs have *no integral apogee* motor. They are launched by a Titan-IIIC, or –34D, with a separate upper stage that can place one or two satellites directly into synchronous orbit.

The usual DSCS constellation consists of four operating satellites located in geosynchronous orbits to provide worldwide capability, and two on-orbit spares. The spares are generally not-yet-activated new satellites. However, older satellites that may have suffered some degradation in performance are also retained as spares.

The DSCS satellites in use at any one time may represent two generations of technology. For example, as of June 1983, the DSCS operational constellation consisted of three DSCS-II satellites and one DSCS-III. Four other DSCS-II satellites were in orbit and available as spares, although two had experienced partial failures.

DSCS-III

As the DSCS system matured, there was a steady increase in the number and variety of ground terminals. Third-generation DSCS-III satellites are being developed and procured to operate in the middle and late 1980s, when a majority of the terminals are projected to be small, transportable, or shipboard types.

The primary DSCS-III communication subsystem has eight antennas that can be connected in various ways to six transponders. The transponders can be used with either frequency-division or time-division multiple access transmissions. Complex switching arrangements allow each transponder a choice of receiving antennas, transmitting antennas, and either a 10-watt or a 40-watt TWTA.

There are three receiving antennas: two earth coverage horns and one advanced multibeam antenna (MBA). Four of the six transponders can be connected to the receive MBA. This antenna forms beams of desired size, shape, and location by using a beam-forming network to control the relative amplitudes and phases of each of 61 individual beams. It can also form nulls in selected directions to counter jamming.

Transmit antennas include two 19-beam MBAs, two earth coverage horns, and a high-gain parabolic dish. Two transmitters are always connected to the horns; the other four may all be connected to the MBAs. These antennas have the same capabilities as the receive MBA except nulling. Three of the channels can also be switched to the parabolic dish, which generates a single beam with high effective radiated power.

An Air Force Satellite Communications (AFSATCOM) System single channel transponder (SCT) provides a secondary communication subsystem on the DSCS-III. The SCT has its own UHF transmitting and receiving antennas, but also can be connected to the 8/7 GHz earth coverage or MBA receiving antennas. The SCT has some on-board processing capability—it demodulates the received uplink and remodulates it for transmission—and it can also store messages for repeated transmission. The uplink has some protection against jamming.

The DSCS-III satellite, like the ISAT-V, is three-axis stabilized. All antennas are mounted on the earth-viewing face of the body and do not require deployment. Sun tracking solar arrays are deployed in orbit from the north and south faces of the satellite. The tracking, telemetry, and control subsystem has an UHF section for use with the SCT plus an 8/7 GHz section for use with the communications terminals. This provision gives redundant command paths into the satellite and allows the communications users direct control of the antennas and transponders.

The first DSCS-III development spacecraft was paired with a DSCS-II spacecraft on a Titan-34D/IUS launch in October 1982, and has been operating successfully.

Appendix C

TABLES SUPPORTING THE PRICE ANALYSES

Table C.1

SUMMARY OF INTELSAT SPACE SEGMENT PRICES
(Millions of then-year dollars)

		System Prices				Total
Program	Qty	Basic Delivery	Performance Incentives	Total	Launch Price	Program Price
I	1	6.5	3.0	9.5	4.4	13.9
II	5	14.0	5.5	19.5	17.9	37.4
III	8	47.7	8.7	56.4	41.6	98.0
IV	8	80.2	32.3	112.5	143.9	256.4
IV-A	3	60.4	12.5	72.9	67.6	140.5
IV-A	3	46.5	6.6	53.1	76.8	129.9
V	9	270.4	84.3	354.7	355.2	709.9
V-A	6	169.0	55.8	224.8	339.4	564.2
VI	5	526.8	112.0	638.8	--	638.8

SOURCE: Information obtained from INTELSAT in February 1983. The original INTELSAT summary table was dated September 8, 1982.

NOTE: We assume all spacecraft are launched and earn full incentives. Launch prices are complete through INTELSAT IV-A and are estimated for IV-A follow-on, V, and V-A (NASA). Launch prices for INTELSAT V include three Ariane launches totaling (fixed price) $82.2 million. No launch prices have been included for the INTELSAT VI program. However, it is assumed, for planning purposes, that the basic program of five spacecraft will use two STS and three Ariane-4 launches.

Table C.2

PRICES IN THE INTELSAT II CONTRACT
(Then-year dollars)

Description	Price	Percent	
Originally contracted items			
1 test model spacecraft	nps	-	-
4 flight spacecraft	8,680,000	84	64
Flight model spares	390,000	4	3
2 ground station telemetry and command equipment sets	680,000	7	5
GS T&C equipment sparesa	60,000	1	-
Spacecraft qualification and accept test plan	nps	-	-
GS T&C accept test plan	nps	-	-
Launch services	520,000	5	4
Subtotal for original items	10,330,000	100	76
Additions to the contract			
Purchase 1 flight spacecraft (F-5)	2,282,700		17
Purchase 1 transponder	300,000		2
Flight apogee motor and spare nozzle	126,446		1
Test F-5	40,550		-
Design, build, and test 2 squinted beam flight antennas	249,566		2
(Total new equipment)	(2,999,262)		(22)
Mods, operation, and maintenance of GS T&C equipment	188,371		1
Study, modify, and test apogee motor	73,554		1
(Total mods and changes)	(199,270)		(1)
Subtotal of added items	3,261,187		24
Total of amended contract	13,591,187		100

SOURCE: Calculations on data from the INTELSAT II contract and amending documents. Contract is closed.

NOTE: GS T&C stands for ground station telemetry and control equipment. "nps" indicates an item was not priced separately.

Table C.3

PRICES IN THE INTELSAT III CONTRACT

(Then-year dollars)

Description	Price	Percent	
Originally contracted items			
2 engineering model spacecraft	10,084,728	32	21
Program management and system engineering	6,603,821	21	14
1 prototype spacecraft	5,716,794	18	12
6 flight spacecraft	3,513,463	11	7
Spacecraft test equipment	2,024,600	6	4
GS T&C equipment sets	1,662,135	5	4
Apogee motors	1,387,293	4	3
Flight spacecraft spare parts	826,539	3	2
GS T&C equipment spares	116,444	-	-
Spacecraft qualification test plan	15,817	-	-
Spacecraft system test equip. test plan	10,708	-	-
GS T&C equip. accept test plan	20,658	-	-
Subtotal for original items	31,985,000	100	68
Additions to the contract			
Purchase F-7	3,932,750		8
Purchase F-8	7,500,000		16
Launch support, etc.	1,369,700		3
Additional spares	3,571		-
Total additional spacecraft	(12,806,021)		(27)
Increase prices, F-1,2,3,4,5,6	1,664,267		4
Increase price, GS T&C equip.	16,260		-
Total price increases	(1,680,527)		(4)
Guidance and control operation and maintenance courses	26,000		-
Transport F-4	23,219		-
Hydrazine valves and thrusters	100,000		-
Apogee motor spin test	17,649		-
Unknown	456,907		1
Total miscellaneous	(623,775)		(1)
Subtotal of added items	15,110,323		32
Total of amended contract	47,095,323		100

SOURCE: Calculations on data from the INTELSAT-III contract. Last amendment was dated November 1969.

Table C.4

PRICES IN THE INTELSAT IV CONTRACT
(Then-year dollars)

Description	Price	Percent	
Originally contracted items			
1 prototype spacecraft	20,128,500	37	25
4 Flight spacecraft	26,434,800	48	33
Spacecraft spares and test equip.	3,320,100	6	4
T&C equipment	1,401,000	3	2
Apogee motors	1,674,900	3	2
Launch support services	846,000	2	1
Drawings and documentation	677,700	1	1
Components for subsystem evaluation	318,600	-	-
Subtotal for original items	54,801,600	100	68
Additions to the contract			
Extend time for spacecraft buy option	100,000		-
Four spacecraft and apogee motors	20,908,000		26
Launch support services	846,000		1
T&C equipment and spares	340,000		-
Total new equipment	(22,194,000)		(28)
Thermal test vehicle	475,900		1
Modify apogee motors	320,700		-
Switches and wiring	16,800		-
Switches and wiring	7,076		-
Extended BAPTA[a] life tests	40,554		-
Extended slip ring test	49,576		-
Special torque testing of F7-F8	4,671		-
Disassemble and test BAPTA, F6-F8	96,858		-
Disassemble and test BAPTA No. 4	7,000		-
Total new tests	(1,019,135)		(1)
Add 3rd earth sensor per spacecraft	350,000		-
Add BAPTA accelerometer and assoc. equip.	275,000		-
Eng. changes to unlaunched spacecraft	669,000		1
Add 3rd BAPTA heater to F1,F4-F8	14,700		-
Modify APM and encoder wiring	5,200		-
Add capability for cross-switching	50,500		-
Ensure telemetry word 62 = zero	2,400		-
Install new batteries and equip. in F1	714,000		1
Install IVA batteries in F6,F8	145,000		-
Modify apogee motor igniters, F1,F6,F8	19,000		-
Launch vibration gear, F6, F8	121,200		-
Total additions and modifications	(2,366,000)		(2)
Study derivative INTELSAT IV spacecraft	490,000		1
Amend study of follow-on spacecraft	70,000		-
Total follow-on study	(560,000)		(1)
Subtotal of added items	26,139,135		32
Total of amended contract	80,940,735		100

SOURCE: Calculations on data obtained from INTELSAT. Last amendment to this contract was dated November 1974.

[a]Bearing and power transfer assembly.

Table C.5

PRICES IN THE INTELSAT IV-A CONTRACT
(Then-year dollars)

Description	Price	Percent	
Originally contracted items			
Development work	14,654,800	24	14
3 flight spacecraft + apogee motors	39,569,653	66	39
Flight spacecraft spare parts	2,052,000	3	2
Spacecraft test equipment	2,289,600	4	2
5 IV-A mod kits (with spares) for GS and CC T&C equipment	10,000	-	-
2 launch support services	571,300	1	1
Equipment for evaluation	650,300	1	1
Total originally contracted	59,817,653	100	58
Changes affecting price			
3 additional spacecraft and motors	40,430,900		40
2 launch support services	626,000		1
CC equipment and spares	331,014		-
9 synchronous command generators	495,000		-
Total new equipment	(41,882,914)		(41)
Install launch vibration on F1--F6	179,000		-
Receiver modifications on F1--F6	975,000		1
Third nutation damper for F1--F6	159,000		-
Total additions and modifications	(1,313,111)		(1)
Cross-polarization test on F2,F3	803,000		1
Storage and condition of batteries, F3--F4	12,680*		-
Reduce office space	-40,000		-
Reduce spacecraft price	-1,500,000		-1
Total miscellaneous	(-724,320)		(-1)
Total items added to contract	42,471,705		42
Total of amended contract	102,289,358		100

SOURCE: INTELSAT IV-A contract.

NOTE: Items marked with an * are estimates; final price will depend on actual months of storage. CC is command and control. Last amendment to this contract was dated July 1981.

Table C.6

PRICES IN THE INTELSAT V AND VA CONTRACTS

(Then-year dollars)

Description	Price	Percent	
Originally contracted items			
Development work	44,494,412	25	10
7 flight spacecraft + apogee motors	25,243,517	71	29
Command equipment	278,258	-	-
Command equipment spares	41,221	-	-
Additional batteries	325,215	-	-
Equipment for evaluation	2,434,352	1	1
Ship and storage containers	144,352	-	-
7 launch support services	2,327,584	1	1
Documentation	1,357,616	1	-
Critical item test items	nps	-	-
Orbiter-mounted equipment	nps	-	-
Total originally contracted	176,646,527	100	40
Changes affecting price			
Improvement of original spacecraft			
GEOIR heaters for F-1--F-8	293,400		-
Ariane launch compatibility for F-4,5,6,7	3,122,000		1
Nickel-hydrogen batteries for F-5,6,7	2,410,000		1
Maritime communication system for F-5,6,7	20,133,000		5
Batteries for F-5,6,7	1,932,000		-
More command equipment	196,733		-
Total major improvements to original spacecraft	(28,087,133)		(6)
Development of improved apogee motor	4,230,000		1
Additional spacecraft and equipment			
F-8 with improved apogee motor and Ariane compatability	27,345,773		6
Nickel-hydrogen batteries for F-8	174,754		-
F-9 spacecraft	22,976,000		5
F-10, F-11, F-12 (I-VA spacecraft)	98,000,000		22
F-13, F-14, F-15 (I-VA spacecraft)	68,804,151		16
Launch services for additional spacecraft	2,245,431		1
Total additional equipment	(219,546,109)		(50)
Miscellaneous	4,313,528		1
Unknown (amendment 21)	3,657,500		1
Subtotal for items added to contract	259,834,270		60
Total of amended contract	436,480,797		100

SOURCE: INTELSAT V contract and amendments, as of September 1982.

NOTE: Several amendments discussed fuel slosh tests that were to be done by NASA. They required the contractor's coordination but were not priced, and would be paid by INTELSAT directly to NASA.

Table C.7

PRICES IN THE INTELSAT VI CONTRACT
(1982 dollars)

Item	Qty	Description	Price	Percent
Originally contracted items				
1	Lot	Development and hardware	174,495,533	33
2	5	Flight spacecraft + apogee motors	296,731,246	57
3	2	Perigee stages (STS)	20,251,847	4
4	Lot	Equipment for evaluation	8,631,730	2
5	3	Shipping and storage containers	440,730	
6	Lot	Documentation	495,514	
7	Lot	Ground support equipment	2,117,892	
8	Lot	Airborne support equipment	12,081,281	2
9	Lot	Spare parts	1,583,006	
10	2	Launch support services, STS	1,897,109	
11	3	Launch support services, Ariane	3,609,569	1
12	3	More surface transportation	245,400	
		Subtotal for original items	518,550,491	99
Changes affecting price				
1	Lot	Add autonomous attitude control, incl. steering for 14/11 GHz spot beam antennas	2,991,921	
2	Lot	Delete some work items	-713,582	
4	Lot	Delete some work items	-462,173	
		Revise billing milestones	-	
1	5	Add nonredundant channelized I-5/5A sparing function compatibility	2,214,000	
		Subtotal for items added to contract	4,030,166	1
Total of amended contract			522,580,657	100

SOURCE: INTELSAT VI contract and amendments, as of March 1983.

NOTE: Prices in this contract were expressed in 1982 currencies (American, Canadian, English, French, German, Italian, and Japanese) and specific escalation indexes were cited. We converted all currencies to U.S. dollars using exchange rates from *International Financial Statistics*, June 1982, p. 14.

Table C.8

INTELSAT LAUNCHES

Series	Serial	Date	Vehicle	Status
ISAT-I	F-1	4/ 6/65	TAD	Successful
ISAT-II	A	10/26/66	TAD	Failed, apogee motor malfunction
	B	1/11/67	TAD	Successful
	C	3/22/67	TAD	Successful
	D	9/27/67	TAD	Successful
ISAT-III	F-1	9/18/68	LT-Delta	Failed, pitch rate malfunction
	2	12/18/68	LT-Delta	Successful
	3	2/ 5/69	LTTA-Delta	Successful
	4	5/21/69	LTTA-Delta	Successful
	5	7/25/69	LTTA-Delta	Failed, 3rd stage malfunction
	6	1/15/70	TAT-Delta	Successful
	7	4/23/70	TAT-Delta	Successful
	8	7/23/70	TAT-Delta	Failed, apogee motor malfunction
ISAT-IV	F-2	1/26/71	Atlas Centaur	Successful
	3	12/19/71	Atlas Centaur	Successful
	4	1/23/72	Atlas Centaur	Successful
	5	6/13/72	Atlas Centaur	Successful
	7	8/23/73	Atlas Centaur	Successful
	8	11/21/74	Atlas Centaur	Successful
	6	2/20/75	Atlas Centaur	Failed, launch vehicle malfunction
	1	5/22/75	Atlas Centaur	Successful
ISAT-IVA	F-1	9/26/75	Atlas Centaur	Successful
	2	1/29/76	Atlas Centaur	Successful
	4	5/26/77	Atlas Centaur	Successful
	?	9/29/77	Atlas Centaur	Failed, launch vehicle malfunction
	3	1/ 7/78	Atlas Centaur	Successful
	6	3/31/78	Atlas Centaur	Successful
ISAT-V	F-2	12/ 6/80	Atlas Centaur	Successful
	1	5/23/81	Atlas Centaur	Successful
	3	12/15/81	Atlas Centaur	Successful
	4	3/ 4/82	Atlas Centaur	Successful
	5	9/28/82	Atlas Centaur	Successful
	6	5/19/83	Atlas Centaur	Successful
	7	10/18/83	Ariane	Successful
	8	3/ 5/84	Ariane	Successful
	9	6/ 9/84	Atlas Centaur	Failed, Centaur failure

SOURCE: TRW Space Log, Twenty-Fifth Anniversary Issue.

NOTE: TAD stands for Thrust Augmented Delta; LT for Long Tank; LTTA for Long Tank Thrust Augmented; and TAT for Thrust Augmented Thor.

Table C.9

SUMMARY OF ON-ORBIT PERFORMANCE OF INTELSAT SPACECRAFT

Spacecraft	Delivery Date: Original	Delivery Date: If Amended	Launch Date	Primary Service Removed	Orbital Performance
ISAT-I					
F-1	ni	ni	4/65	1/69	Apparently satisfactory
F-2	ni	ni			(Never launched)
ISAT-II					
F-1	7/66		10/66		(Apogee motor failure)
F-2	8/66		1/67	4/69	Control problem 6/68, out of fuel 3/69
F-3	9/66		3/67	1/70	Mostly satisfactory
F-4	10/66		9/67	2/69	Control problems
F-5	3/68				(never launched)
ISAT-III					
F-1	ni	ni	9/68		(Pitch-rate malfunction)
F-2	ni	ni	12/68	3/70	Antenna spinning 3/70
F-3	ni	ni	2/69	9/72	Low gain 3/69--6/71
F-4	ni	ni	5/69	7/72	MDA stalled 11/72
F-5	ni	ni	7/69		(3rd-stage failure)
F-6	ni	ni	1/70	5/71	Many antenna problems
F-7	1/70	2/70	4/70	1/72	TWT failed 3/71; MDA stall 1/72
F-8	7/70		7/70		(Apogee motor failed)
ISAT-IV					
F-1 1	8/70	10/74	5/75	11/82	Nearly completely satisfactory
F-2 1	10/70	2/71	1/71	11/73	One TWT failed 6/73
F-3 1	1/71	7/71	12/71	1/79	Satisfactory
F-4 1	3/71	10/71	1/72	12/74	Satisfactory
F-5 2	10/71	7/71	6/72	4/80	Satisfactory
F-6 2	1/72	2/72	2/75		(Launch vehicle failure)
F-7 2	5/72		8/73	1/83	MDA temporarily stalled 3/74, ok otherwise
F-8 2	8/72		11/74	2/82	MDA temporarily stalled 4/75, ok otherwise
ISAT-IVA					
F-1 1	5/75	8/75	9/75	so	Satisfactory
F-2 1	8/75	11/75	1/76	so	Satisfactory so far
F-3 1	11/75	3/76	1/78	so	Satisfactory so far
F-4 2	12/76		5/77	so	Satisfactory so far
F-5 2	6/77		9/77		(Launch vehicle failure)
F-6 2	12/77		3/78	so	Satisfactory so far

SOURCES: Contracts for INTELSAT spacecraft and INTELSAT reports on *Monthly Technical Status Report for INTELSAT Satellites in Orbit*, January 1969 through June 1983.

NOTE: "ni" indicates we have no information on an item; MDA stands for mechanically despun antenna; TWT stands for traveling wave tube; rec indicates a receiver; and "so" indicates a spacecraft was still operating as of June 30, 1983.

Table C.10

ESTIMATED PROFILE OF PAYMENTS FOR INTELSAT SPACECRAFT
(Millions of then-year dollars)

Fiscal Year	INTELSAT I	II	III	IV	IVA	V/VA	IV
1965	6.5						
1966							
1967		10.7	15.0				
1968		0.3	15.7				
1969		2.3	4.3	18.4			
1970			0.4	27.1			
1971			3.0	22.9			
1972			5.0	6.9			
1973			2.9	3.8	1.1		
1974			0.6	0.8	29.7		
1975			0.1	0.7	32.9		
1976			0.1		26.4		
1976T					2.7		
1977					7.7	44.8	
1978					1.1	53.8	
1979						59.8	
1980					0.2	151.1	
1981						117.5	
1982					0.5	1.3	522.6
1983						7.3	
1984						0.5	
1985						0.4	
Total	6.5	13.3	47.1	80.6	102.3	436.5	522.6

SOURCE: Analysis of INTELSAT contracts and amendments.

NOTE: I-3 payments are net of $0.2 million schedule penalty in 1969 and $1.1 million penalty in 1970. I-5 payments are net of $2.3 million schedule penalty in 1981, $3.5 million penalty in 1982, and $2.3 million penalty in 1983.

Table C.11

ESTIMATED PROFILE OF PAYMENTS FOR INTELSAT LAUNCHES
(Millions of then-year dollars)

Fiscal Year	INTELSAT						
	I	II	III	IV	IVA	V/VA	VI
1965	4.4	0	0	0	0	0	0
1966	0	4.5	0	0	0	0	0
1967	0	9.0	0	0	0	0	0
1968	0	4.5	0	0	0	0	0
1969	0	0	20.9	0	0	0	0
1970	0	0	20.9	0	0	0	0
1971	0	0	0	18.0	0	0	0
1972	0	0	0	36.0	0	0	0
1973	0	0	0	18.0	0	0	0
1974	0	0	0	18.0	0	0	0
1975	0	0	0	54.0	0	0	0
1976	0	0	0	0	48.1	0	0
1977	0	0	0	0	48.1	0	0
1978	0	0	0	0	48.1	0	0
1979	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0
1981	0	0	0	0	0	78.9	0
1982	0	0	0	0	0	78.9	0
1983	0	0	0	0	0	78.9	0
1984	0	0	0	0	0	78.9	0
1985	0	0	0	0	0	96.1	0
1986	0	0	0	0	0	113.1	66.9
1987	0	0	0	0	0	113.1	144.6
1988	0	0	0	0	0	56.6	156.3
Total	4.4	18.0	41.8	144.0	144.3	694.5	367.8

SOURCE: INTELSAT fact sheet, TRW Space Log, INTELSAT BG-55-36E W/6/83 (Attachment 1), dated 16 June 1983, and recent estimates of shuttle costs for 1986 and beyond.

Table C.12

ESTIMATED PROFILE OF PAYMENTS OF INTELSAT INCENTIVES
(Millions of then-year dollars)

Fiscal Year	INTELSAT I	II	III	IV	IVA	V/VA	VI
1965	0	0	0	0	0	0	0
1966	0	0	0	0	0	0	0
1967	3.0	0	0	0	0	0	0
1968	0	2.6	0	0	0	0	0
1969	0	0.8	4.4	0	0	0	0
1970	0	0.2	0.8	0	0	0	0
1971	0	0	0.8	1.5	0	0	0
1972	0	0	0.6	6.3	0	0	0
1973	0	0	0.1	4.1	0	0	0
1974	0	0	0	4.0	0	0	0
1975	0	0	0	6.5	0	0	0
1976	0	0	0	3.9	8.4	0	0
1977	0	0	0	0.8	2.2	0	0
1978	0	0	0	0.8	8.6	0	0
1979	0	0	0	0.4	0	0	0
1980	0	0	0	0.3	0	0	0
1981	0	0	0	0.3	0	1.7	0
1982	0	0	0	0.2	0	4.1	0
1983	0	0	0	0	0	6.6	0
1984	0	0	0	0	0	9.2	0
1985	0	0	0	0	0	11.6	0
1986	0	0	0	0	0	14.4	0
1987	0	0	0	0	0	16.8	15.4
1988	0	0	0	0	0	17.7	23.1
1989	0	0	0	0	0	15.7	0
1990	0	0	0	0	0	13.3	0
1991	0	0	0	0	0	10.7	0
1992	0	0	0	0	0	8.2	6.2
1993	0	0	0	0	0	5.6	15.6
1994	0	0	0	0	0	2.8	15.0
1995	0	0	0	0	0	0.7	14.2
1996	0	0	0	0	0	0	14.2
1997	0	0	0	0	0	0	8.5
Total	3.0	3.6	6.7	29.1	19.2	139.1	112.2

SOURCE: Analysis of INTELSAT contracts, amendments, and On-orbit Status Reports.

NOTE: Entries are estimated payments for ISAT-I through ISAT-VIA, and maximum incentives for ISAT-V/VA and ISAT-VI.

Table C.13

BACKUP INFORMATION FOR TABLE A.16

Item	I	II	III	IV	IVA
Price (millions of 1983 $)	53	125	311	661	491
Spacecraft paid for	2	5	8	8	6
Spacecraft that worked	1	3	5	7	5
Circuits	240	240	1500	3750	6000
Months of operation	45	84	133	559+	353+
Circuit months (thousands)	10.8	20.2	199.5	2096+	2118+
Ave price ($/circuit month)	4907	6200	1559	<315	<232

Item	V	VA	V/VA	VI
Price (millions of 1983 $)			1297	813
Number of spacecraft	9	6	15	5
Circuits	12,000	15,000		40,000
Design life (months per spacecraft)	84	84		120
Design circuit months (millions)	9.1	7.6	16.6	24.0
Ave price ($/circuit month)			78	34

SOURCE: Price and quantity information from Tables 9 and 12; circuit estimates from *INTELSAT Is*, brochure published by INTELSAT (not dated).

Table C.14

PRICES IN THE INITIAL DSCS-II CONTRACT
(Millions of then-year dollars)

Item	Target Cost	Target Profit	Target Price	Ceiling Price
Contract				
1 RDT&E	26.50	2.95	29.45	
2 Data and reports	0.19	0.02	0.21	
3 Long lead-time articles	7.21	0.79	8.00	
Subtotal	33.89	3.76	37.65	40.67
Options				
4 Produce 6 flight spacecraft	30.00	3.30	33.30	36.00
5 Production data	0.31	0.03	0.35	0.38
0 Launch support	0.17	0.02	0.19	0.21
Subtotal	30.48	3.35	33.84	36.58
Total (w/o item 3)	57.17	6.32	63.49	68.61

SOURCE: DSCS-II development contract (without changes), now closed.

NOTE: Target profit appears to be 11 percent of target cost, and the ceiling price appears to be 20 percent higher than the target cost. Item 3 is not to be used if option 4 is selected. Totals include options 4 and 5, but not 3, and assume the ceiling price for item 3 to be 120 percent of the target cost.

Table C.15

PRICES IN THE DSCS-II REPLENISHMENT CONTRACT
(Millions of then-year dollars)

Description	Target Price	Percent
Originally contracted items		
Main item, including F7--F12	72.85	36
Data and reports	0.41	-
Total original items	73.26	(36)
Additions to the contract		
Changes to the main item	10.57	5
Adopt launch operations options	1.91	1
Buy F-13 and F-14		
Spacecraft	40.58	20
Launch operations	0.84	-
Royalty	0.02	-
Total F-13 and F-14	(41.44)	(21)
Buy F-15		
Spacecraft	19.72	10
Launch operations	1.55	1
Storage	9.55	5
Total F-15	(30.82)	(15)
Buy F-16		
Spacecraft	25.95	13
Launch operations	1.99	1
Storage	6.80	3
Total F-16	(34.74)	(17)
TWTA mod and retrofit (all spacecraft)	7.66	4
Other	1.49	1
Total current contract	201.90	100

SOURCE: Calculations on data from DSCS-II replenishment contract, original and conformed versions.

NOTE: "Current" price is as of May 1983. The September 30, 1983, price discussed in App. B was $199 million.

Table C.16

PRICE CHANGE IN THE DSCS-III DEVELOPMENT CONTRACT

(Millions of then-year dollars)

Item	Description	Price	Percent	
Originally contracted items				
1	2 demonstration flight satellites	68.6	39	90
	Command system simulator and program	1.0	1	1
	Command program	0.4	-	1
	Electromagnetic compatability software	0.1	-	-
	Launch operations	1.0	1	1
	Orbital support	1.2	1	2
	Engineering development models	3.5	2	5
	T & C programs	0.5	-	1
2	Data and reports	0.2	-	-
	Total original items	76.6	(44)	100
Additions and changes to items 1 and 2				
1	TWTA mods, testing, and depotting	9.0	5	
	AFSATCOM single channel transponder	6.6	4	
	SCT SHF downlink	8.5	5	
	F-1 storage and retesting	7.1	4	
	Batson II integration	6.9	4	
	Gimbal dish antenna work	2.3	1	
	Survival testing	1.4	1	
	Solid state amplifier integration	0.7	-	
	Miscellaneous	12.0	7	
	Total changes to items 1 and 2	55.4	(32)	
Cost increases on items 1 and 2		21.9	13	
Other additions to the contract				
5,6 Lot	Launch vehicle integration	12.1	7	
7 Lot	DSCS command program software	0.9	1	
8 Lot	Develop 10 W solid state amplifier	3.4	2	
9 Lot	Support IRR and MRR	0.7	-	
10 Lot	STS avionics mods	3.4	2	
	Total other additions	20.5	(12)	
Total contract change		97.8	(56)	
Total current contract		174.1	100	

SOURCE: DSCS-III development contract, Cost Performance Report dated August 19, 1983, and discussions with DSCS SPO personnel.

Table C.17

PRICE CHANGE IN THE DSCS-III REFURBISHMENT CONTRACT
(Millions of then-year dollars)

Description	Price	Percent
Original contract		
Long-lead items	13.15	20
Additions to the contract		
Refurbish DSCS-III A3 spacecraft	31.15	47
STS/IUS compatability	17.92	27
Redundant jammer-locater electronics	2.47	4
Increase computer memory	0.24	-
Final spares	0.62	1
Telemetry equipment	0.26	-
Other	0.47	1
Total additions	53.13	80
Total current contract	66.28	100

SOURCE: DSCS-III refurbishment contract as of September 30, 1983.

Table C.18

PRICE CHANGE IN THE DSCS-III PRODUCTION CONTRACT
(Millions of then-year dollars)

Item	Qty	Description	Price	Percent
Originally contracted items				
1	Lot	Master parts lists 1-17	45.96	14
2	Lot	Data and reports	nps	
Total original items			45.96	(14)
Price/scope increases on original items			5.36	2
Additions to the contract				
3	Lot	Parts testing and analysis	2.89	1
4	Lot	DSCS III-B4 and DSCS III-B5	94.74	28
5	Lot	Flight adapter set	0.06	-
6	Lot	III-B4 development	30.43	9
7	Lot	Data and reports (3020 funds)	nps	
8	1	Launch vehicle integration	25.49	8
9	Lot	Data and reports	nps	
10	Lot	DSCS III-B6, -B7	126.34	37
11	1	III-B6/B7 flight adaptor set	nps	
12	Lot	Data and reports	nps	
		Other	4.60	1
Total additions			284.56	(84)
Total current contract			335.88	100

SOURCE: DSCS-III production contract.

Table C.19

DSCS LAUNCHES

Series	Serial	Date	Vehicle	Status
IDCSP	1-7	6/16/66	Titan IIIC	Successful
	8-15	8/26/66	Titan IIIC	Booster malfunctioned
	16-23	1/18/67	Titan IIIC	Successful
	24-26	7/1/67	Titan IIIC	Successful
	27-34	6/13/68	Titan IIIC	Successful
DSCS-II	1-2	11/ 3/71	Titan IIIC	Successful
	3-4	12/13/73	Titan IIIC	Successful
	5-6	5/20/75	Titan IIIC	Transstage malfunction
	7-8	5/12/77	Titan IIIC	Successful
	9-10	3/25/78	Titan IIIC	Failed
	11-12	12/14/78	Titan IIIC	Successful
	13-14	11/21/79	Titan IIIC	Successful
	16[a]	10/30/82	Titan 34D/IUS	Successful

SOURCE: TRW Space Log, Twenty-Fifth Anniversary Issue.

[a]DSCS-II F-16 was paired with DSCS-III A-1 on an IUS used as the final stage of a Titan-340 rocket. DSCS-II F-15 is scheduled to be paired with DSCS-III A-2 on a Transtage carried aloft by the Titan 34-D.

Table C.20

ESTIMATED PROFILE OF PAYMENTS FOR DSCS SPACECRAFT
(Millions of then-year dollars)

Fiscal Year	DSCS-II Initial	DSCS-II Replacement	DSCS-III Develop	DSCS-III Refurbish	DSCS-III Produce
1965	0	0	0	0	0
1966	0	0	0	0	0
1967	0	0	0	0	0
1968	0	0	0	0	0
1969	2.7	0	0	0	0
1970	42.6	0	0	0	0
1971	17.8	0	0	0	0
1972	7.1	0	0	0	0
1973	2.7	0	0	0	0
1974	4.8	0	0	0	0
1975	-0.1	7.8	0	0	0
1976	0.7	45.5	0	0	0
1976T	0	0	0	0	0
1977	0.0	38.3	0	0	0
1978	0.2	35.0	19.9	0	0
1979	0	17.0	28.9	0	0
1980	0	17.4	39.1	0	0
1981	0	9.9	40.8	12.9	0
1982	0	8.9	16.4	16.7	56.3
1983	0	14.4	10.6	11.9	24.6
1984	0	4.6	7.9	11.4	133.1
1985	0	0	5.3	8.0	84.1
1986	0	0	2.7	7.2	41.0
1987	0	0	1.3	0	10.4
1988	0	0	1.3	0	0
Totals	78.5	198.8	174.2	68.1	349.6

SOURCE: Analysis of DSCS contracts, AFPRO records, Space Division and AMIS accounts, and other SPO records.

NOTE: DSCS-III refurbishment contract figures include potential award fees of $0.6 million for 1984, 1985, and 1986; DSCS-III production contract figures include actual $3.7 million award fee for 1983. Later years assume full potential awards: $2.9 for 1984; $2.9 for 1985; $2.72 for 1986; and $1.5 for 1987.

Table C.21

ESTIMATED PROFILE OF PAYMENTS FOR DSCS LAUNCHES
(Millions of then-year dollars)

Fiscal Year	DSCS-II	DSCS-III
1972	29.0	0
1973	0	0
1974	29.0	0
1975	29.0	0
1976	0	0
1977	29.0	0
1978	29.0	0
1979	29.0	0
1980	29.0	0
1981	0	0
1982	0	0
1983	14.5	14.5
1984	14.5	14.5
1985	0	98.8
1986	0	160.0
1987	0	80.0
Total	232.0	367.8

SOURCE: Information from DSCS SPO, TRW Space Log, and NASA shuttle tariffs.

Table C.22

ESTIMATED PROFILE OF PAYMENT FOR DSCS ON-ORBIT INCENTIVES
(Millions of then-year dollars)

Fiscal Year	Estimated Payments: DSCS-II Maximum	DSCS-II Actual[a]	DSCS-III Maximum
1972	0.23	-1.425	0
1973	0.91	0	0
1974	1.60	0	0
1975	1.94	0.114	0
1976	1.03	0.380	0
1977	0	0.456	0
1978	0	0.513	0
1979	0	0	0
1980	2.20	0.852	0
1981	2.75	1.066	0
1982	4.40	5.854	0
1983	5.07	4.729	3.37
1984	4.52	3.466	1.29
1985	1.84	1.840	2.79
1986	1.84	0.780	2.79
1987	0	0	2.79
1988	0	0	2.79
1989	0	0	2.79
1990	0	0	2.79
1991	0	0	2.79
1992	0	0	2.79
1993	0	0	1.50
1994	0	0	1.50
Total	28.33	18.625	29.98

SOURCE: Information from DSCS SPO and TRW Space Log.

[a]"Actual" incentives include estimates of full incentives for future operations of F-11 through -16.

Appendix D

SENSITIVITY OF PRESENT VALUES TO ESCALATION FACTORS

The first two tables in this appendix contain alternative AF Space Division, Department of Defense, and general economic escalation factors. Those contained in Table D.1 have been developed specifically for Air Force spacecraft; they were used in all computations reported in the text and in Apps. A and B.

Table D.3 compares the results of the various indexes when used to escalate the INTELSAT and DSCS spacecraft prices to 1983 dollars. The ISAT-VI price is used as the base in these comparisons since its payment profile (see Table C.10) is the most simple and hence the least susceptible to distortion when escalated.

Table D.3 shows that the choice of escalating index does affect the estimated spacecraft price, in some cases by as much as 10 percentage points. The three military indexes produce rather close results. The Space Division index, being the most specialized, is obviously the preferred choice for this and future spacecraft work.

Table D.1

ESCALATION AND INFLATION FACTORS

Fiscal Year	Spacecraft Production Cost Index
1965	3.881
1966	3.757
1967	3.632
1968	3.497
1969	3.309
1970	3.086
1971	2.903
1972	2.745
1973	2.561
1974	2.333
1975	2.083
1976	1.889
1977	1.704
1978	1.543
1979	1.416
1980	1.264
1981	1.149
1982	1.064
1983	1.000
1984	0.925
1985	0.855
1986	0.792
1987	0.733
1988	0.678
1989	0.627
1990	0.579
1991	0.535
1992	0.495
1993	0.459
1994	0.425
1995	0.394
1996	0.365
1997	0.338

SOURCE: Space Division, Directorate of Cost Analysis.

Table D.2

ESCALATION AND INFLATION FACTORS

Fiscal Year	Department of Defense		General Economic		
	Primary	Alternative	GNP	Machinery Equipment	Electrical Equipment
1965	3.655	3.163	2.98	3.17	2.76
1966	3.525	3.057	2.88	3.08	2.69
1967	3.389	2.958	2.79	2.98	2.62
1968	3.263	2.859	2.68	2.88	2.58
1969	3.093	2.772	2.55	2.79	2.55
1970	2.906	2.666	2.42	2.67	2.46
1971	2.751	2.546	2.31	2.58	2.39
1972	2.621	2.452	2.22	2.52	2.37
1973	2.463	2.354	2.09	2.44	2.33
1974	2.292	2.210	1.92	2.14	2.10
1975	2.046	1.933	1.75	1.84	1.87
1976	1.887	1.810	1.67	1.74	1.79
1977	1.698	1.694	1.58	1.64	1.70
1978	1.572	1.587	1.47	1.52	1.60
1979	1.440	1.459	1.36	1.39	1.46
1980	1.300	1.331	1.23	1.24	1.30
1981	1.172	1.189	1.13	1.13	1.09
1982	1.077	1.084	1.06	1.06	1.10*
1983	1.000	1.000	1.00*	1.00*	1.00*
1984	0.937	0.932	0.94*	0.94*	0.92*
1985	0.877*	0.867	0.88*	0.88*	0.85*
1986	0.822*	0.813	0.83*	0.83*	0.77*
1987	0.770*	0.765	0.78*	0.78*	0.71*
1988	0.721*	0.718	0.73*	0.73*	0.65*

SOURCE: DoD factors synthesized from AFR 173-13, February 1982, Tables 5.1, 5.3, and 5.4.

NOTE: DoD factors apply to U.S. Government fiscal years (July 1 through June 30 for 1965 through 1975; July 1 through September 30 for 1976; and October 1 through September 30 for 1977 through 1990). Non DoD factors apply to calendar years.

*Indicates an estimate we computed by extrapolating the inflation rate between the last two years provided.

Table D.3

SPACECRAFT PRICES EXPRESSED AS PERCENT OF ISAT-VI PRICE, USING ALTERNATIVE ESCALATION INDEXES
(1983 Dollars)

	Escalation Index					
	Space Division	Department of Defense		General Economic		
Spacecraft System	Spacecraft	Spacecraft	General Procurement	GNP	Machinery & Equipment	Electronics Equipment
ISAT-I	4	4	4	3	4	3
ISAT-II	9	8	7	7	7	6
ISAT-III	28	26	23	22	24	21
ISAT-IV	44	41	37	35	38	34
ISAT-IVA	38	36	34	32	34	33
ISAT-V	104	105	106	101	103	102
ISAT-VI	100	100	100	100	100	100
DSCS-II						
Initial	42	39	36	33	37	33
Replenishment	55	55	54	52	53	53
DSCS-III						
Development	38	38	39	37	38	37
Refurbishment	9	9	9	9	9	9
Production	58	58	57	59	59	56
	1983 Prices Relative to Space Division Index					
ISAT-VI	100	101	102	100	100	103

SOURCE: Escalation of payments from Table C.20 using factors from Tables D.1 and D.2.

Appendix E

PAIRING OF PROGRAMS FOR COMPARISON

To determine the consequences of the many differences between the Air Force and INTELSAT in terms of user needs and satellite performance requirements, we selected for comparison two "similar" pairs, each comprising one INTELSAT and one DSCS satellite. ISAT-IV and ISAT-IVA were chosen for comparison with DSCS-II and ISAT-V was compared with DSCS-III. Each of the four satellites is described in additional detail below.

COMPARISON OF ISAT-IV/IVA WITH DSCS-II

We selected the ISAT-IV/IVA systems for comparison with DSCS-II because both families were acquired over similar time spans (1968 through 1980) and both were built using the same technological base. Both families of satellites are spin stabilized in orbit, both employ body-mounted solar cells to supply spacecraft power, and both communications antennas are mounted on despun platforms. ISAT-IV and DSCS-II each have two steerable, parabolic dish antennas capable of focusing spot beams on portions of the globe, and four horn antennas providing global coverage.

Both families of satellites have also undergone similar mid-life changes. DSCS-II underwent a mid-life communication subsystem design change that made the last four satellites different from the first 12 satellites. Similarly, the six ISAT-IVA satellites incorporated communications subsystem design changes that made them different from the eight earlier ISAT-IV satellites.

The most important features of the DSCS-II and ISAT-IV/A satellites are summarized in Table E.1 and described in greater detail below.

The ISAT-IV/IVA Satellites

In October 1968, INTELSAT contracted with the Hughes Aircraft Company for development and production of four ISAT-IV satellites. In July 1970, INTELSAT exercised an option to order four more satellites. The ISAT-IVA program began in April 1973, when INTELSAT ordered development of a modified ISAT-IV spacecraft and the production of three satellites in this new configuration. In December 1974, INTELSAT exercised its option and ordered three additional ISAT-IVA satellites. All 14 satellites were launched by Atlas/Centaur boosters between 1971 and 1978.

From a communications viewpoint, ISAT-IVA is similar to the ISAT-IV, but with two major exceptions. The first difference is that ISAT-IVA employs an antenna array which achieves spatial isolation of the east and west hemispheres of the earth's disk as seen by the satellite. This allows reuse of the 6/4 GHz band and enables the satellite to carry more traffic than the ISAT-IV satellites. Spatcial isolation, which results from contour beam forming, is accomplished by the array of feed horns that illuminate the paraboloid dish. The placement of the feed horns relative to each other and the dish controls the contour that is formed. Since

Table E.1

FEATURES OF INTELSAT-IVA AND DSCS-II SATELLITES

Requirement	INTELSAT IV[a]	DSCS-II[b]
Number of transponders	12[c] (6/4 GHz)	2 (8/7 GHz)
Frequency reuse	No	No
Bandwidth/channel	36 MHz	50 to 185 MHz
Guardband between channels	4 MHz	25 MHz
EIRP		
Earth coverage	23 dBW	31 dBW
Focused beam	35 dBW	40 to 46 dBW
Antenna beam		
Earth coverage	17 deg	> 7.5 deg (entire earth)
Focused beam	4.5 deg	1 deg
Beam repositioning time	15 minutes	5 minutes
Main & side lobe specs	None	-23 dB for > 3.25 deg (focused)
Design life	7 years	5 years
Probability of survival	0.7 that 75% of channels operational after 7 yr	0.5 for 100% spec compliance after 3 yr, following 2 yr of storage
Prelaunch storage life	1 year	3 years
Attitude control	By ground command	+3 deg
Mobility	95 ft/sec, at expense of lifetime	405 ft/sec, one time
Weight (spacecraft only)	1600 lb	1300 lb
Encryption	No	Yes
Hardening	No	Some
Anti-jam	No	Some (electronics resistant)
Redundancy	As needed to meet reliability	No single active component failure will cause mission loss; one spare for each TWTA

[a]See INTELSAT IV Technical Specifications (9 Feb 68).

[b]See Prime Item Development Specification of Defense Communications System, Phase II
(DSCS-II) Space Segment (30 Nov 79).

[c]Later increased to 20 transponders in ISAT-IVA.

the contours are different for each ocean region, three different versions of the satellite were produced.

The second change from ISAT-IV to ISAT-IVA was in the number of transponder channels. The ISAT-IVs had 12 active and 12 redundant transponders, giving, a two for one redundancy. The 12 active 36 MHz transponders, each separated by a 4 MHz guard band, used 476 MHz of the total 500 MHz bandwidth allocation. The redesigned communication subsystem of the ISAT-IVAs contained 20 active and 12 redundant transponders. Eight transponders were connected to the east hemispheric/spot antenna, eight to the west hemispheric/spot, and four to the global transmit horn. This gave a total usable bandwidth of 720 MHz, all contained within the basic 500 MHz allocation. A new switching arrangement allowed the 16 hemispheric/spot-linked transponders to operate with three for two redundancy. The four transponders connected to the global horns retained two for one redundancy.

The DSCS-II Satellites

The DSCS-II program began in March 1969 when the Air Force contracted with TRW, Inc. to develop and build six satellites. In October 1974, a second contract was issued to TRW to build six additional satellites in the same configuration. That contract was later modified to acquire an additional four spacecraft of a modified design. The first 14 DSCS-II satellites were launched by Titan III-C boosters between 1971 and 1979. One satellite was launched in 1982 by a Titan 34D/Inertial Upper Stage booster. The remaining satellite is in storage awaiting a launch requirement. All 16 satellites were manufactured before October 1980.

Like the ISAT-IV, DSCS-II also employs two parabolic dish antennas and four global horn antennas for communication. The satellite has a bandwidth of 485 MHz divided between two transponders.[1] Each channel is tailored to the user of that channel, with the channel bandwidth varying between 50 and 185 MHz. To supply sufficient transmit power for its ground stations to receive its signals, each DSCS transponder channel employs a 20-watt (or 40-watt in later models) TWTA.

At the start of the DSCS-II program, 20-watt 8/7 GHz band TWTAs were the state of the art. In the mid-1970s, 40-watt TWTAs became available and were incorporated into the last four DSCS-II satellites. Except for the higher power levels, those DSCS-II satellites had the same communication subsystem design as the preceding 12 satellites.

Requirement Differences

This comparison of the communication subsystems of ISAT-IV/IVA and DSCS-II indicates that DSCS has more stringent requirements (higher power and greater bandwidth) on each channel but far fewer channels. DSCS-II satellites also require features not needed by their INTELSAT counterparts, such as antijamming. DSCS-II has special tunnel diodes, which required expanded design and test programs during the development phase, and the satellites are equipped to handle encrypted communications and command data. The encryption devices were provided to the DSCS manufacturer by the Air Force but integration, especially the development of electronics buffers to integrate the encryption devices into the satellite electronics, was rather difficult.

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[1]On DSCS-II satellites, each transponder carries two communications channels.

Bus Differences

The ISAT-IV and -IVA use a similar satellite bus (the main body of the spacecraft, providing structure, electrical power, propulsion, thermal control, tracking, telemetry, and attitude control). The main difference between the two is that ISAT-IVA is capable of some limited autonomous station-keeping and attitude control, whereas ISAT-IV is more dependent on ground control (see Table 19).

The DSCS-II satellite bus is similar to the ISAT-IV/IVA bus. However, the DSCS is required to continue functioning without ground command for at least three weeks. Further, the spin-axis must remain fixed for the lifetime of the satellite without ground command. These requirements are generated by the need for DSCS to remain operational, for as long as possible, even if the ground satellite control network is attacked and destroyed. Thus, in general the attitude control system of the DSCS-II satellites is more complex and capable than that of the ISATs.

The DSCS-II bus is also designed to survive a nuclear event in space and to protect the electronics from such an event. Special glass is used on the solar arrays and the structure of the satellite has added protection.

Modification of the last four DSCS-II satellites to accommodate the 40-watt TWTAs also required changes in the thermal control system to handle the added heat load imposed by the larger devices. Structural modifications were required to handle both the larger batteries (to supply power during eclipse periods) and the larger and heavier TWTAs. The size of the solar array was not changed but new, more efficient solar cells were developed to power the new TWTAs and battery charging equipment.

Discussion

How have these differences in performance requirements and design approaches affected the price of the satellites? Unfortunately, it is not possible to answer that question with much precision or confidence. However, a careful examination of the cost and technical data contained in the various contracts and specifications, together with discussions with some of the system developers, yield a few relevant observations.

The greater number of channels for ISAT-IV should pretty much balance the higher cost, but fewer, 20-watt TWTAs in the DSCS-II and its tunnel diodes for antijaming. The DSCS autonomous attitude control capabilities might add about 5 percent to the cost of a DSCS-II. The limited nuclear hardening of the solar cells and structure probably adds another 5 percent. Finally, the electronics buffer for the encryption boxes should add something, but probably no more than 1 percent. Thus, all in all, the added technical requirements that a DSCS-II must satisfy appear to add perhaps 10 percent to its cost.

Since the design differences between the ISAT-IVA and the DSCS-II are much smaller, their cost differences should be also. In this case, the 20 transponder channels with added switching roughly balance the 40-watt 8/7 GHz band TWTAs used on the later DSCS-II satellites. ISAT-IVA uses autonomous attitude control of a nature similar to DSCS-II, so these should roughly cancel out. The electronics buffer interface to the encryption boxes and nuclear hardening requirements for DSCS-II still add about 5 percent to its cost. However, now the ISAT-IVA contour beam-forming antenna network and support structure also add about 5 percent to the cost of that system. Thus, the net result is probably that DSCS-II and ISAT-IVA should cost about the same.

These estimates are quite rough and we do not want to imply that the cost differences are as precise as the some of the above figures might suggest. We conclude only that design differences in the DSCS-II and ISAT-IV/A satellites should account only for cost differences of, at most, a few percent.

COMPARISON OF ISAT-V WITH DSCS-III

Finding an INTELSAT satellite to compare with DSCS-III was more difficult than was identifying ISAT-IV/IVA for comparison with DSCS-II. DSCS-III was initiated in early 1977, only a few months after start of ISAT-V, but pushed technology far harder. ISAT-VI may be more technologically comparable with DSCS-III but was started nearly five years later and is early in its development stage, thus its real cost and schedule remain unknown. Both the ISAT-V and DSCS-III satellites are three-axis stabilized in orbit and employ solar cells mounted on "wings" on each side of a box-shaped body. The communications antennas are mounted on one side of the box which always faces earth. ISAT-VI is spin stabilized. We will thus compare DSCS-III with ISAT-V. The most important features of these satellites are compared in Table E.2 and described in additional detail below.

The ISAT-V Satellite

The ISAT-V program began in September 1976 when INTELSAT contracted with the Aeronutronic Ford Corporation (now called Ford Aerospace and Communications Corporation) for development and production of seven satellites. In June 1979, INTELSAT ordered modifications to the last three satellites, adding a maritime communications package. In April 1980, and again in January 1981, INTELSAT ordered production of one more satellite. In June 1981, and again in May 1982, INTELSAT ordered three more satellites, bringing the total ordered to 15. The first ISAT-V was launched in December 1980 by an Enhanced Atlas/Centaur. ISAT-V can also be launched by Ariane-2 and the space shuttle.

This was the first INTELSAT satellite to use the 14/11 GHz band as well as 6/4 GHz band communications.

Even before launch of the first ISAT-V, it became obvious that still more capacity would be required in the INTELSAT system by the mid-1980s, and planning was started for an advanced version generally referred to as ISAT-VA. Major modifications to the basic ISAT-V design include the provision of three additional cross-polarized global channels and two cross-polarized steerable spot beams. The 6/4 GHz beams are leased to a subsidiary for domestic business service. Design life remains at 7 years.

The DSCS-III Satellite

DSCS-III entered full scale engineering development when the General Electric Corporation was awarded a contract in February 1977. The development contract called for one prototype (nonflyable) and two flight spacecraft. In November 1981, a separate contract was let to GE to modify the prototype into a flight unit. In January 1982, the Air Force ordered two more spacecraft. An additional two satellites were ordered in December 1982. The first DSCS-III was launched in October 1982 by a Titan 34D/IUS booster. DSCS-IIIs can also be launched by the space shuttle.

Table E.2

FEATURES OF INTELSAT-V AND DSCS-III SATELLITES

Requirement	INTELSAT V[a]	DSCS-III[b]
Number of transponders	22 (12 @ 6/4 GHz & 10 @ 14/11 GHz)	6 @ 8/7 GHz
Frequency reuse	4 times @ 6/4 GHz	No
Bandwidth/channel	36 MHz[c]	60 - 85 MHz
Guardband between channels	4 MHz	25 MHz
Channel switching	Channels 1-2 & 5-8 may be interconnected between bands in either direction	Channels frequency conversion fixed
EIRP		
Earth coverage	22 - 25 dBW	23 - 29 dBW
Focused beam	41 - 44 dBW	37 - 44 dBW
Antenna beam		
Earth coverage	Defined by list of stations	1000 + 2000 n mi
Focused beam	3.2 deg by 1.8 deg	1 deg circular
Beam repositioning time	Not specified	1 min (5 min on prototype)
Main & side lobe specs	33 dB isolation > 8 deg 27 dB for > 6.5 deg but > 8 deg	14 dB > 1 deg (transmit) Classified receive
Design life	7 years	10 years
Prelaunch storage life	5 years	2 years
Probability of survival	0.75 that 65% of channels operational after 7 yr in orbit	0.7 that 1/2 of channels including 1 40W channel) will operate after 7 yr in orbit, following 2 yr storage
Attitude control	±1.10 deg in plane and longitude	±0.10 deg in plane and longitude
Autonomy	160 updates per year-maximum	24 updates per year-maximum
Mobility	95 ft/sec, at expense of lifetime	27 ft/sec, one time
Weight (spacecraft only)	2000 lb	2500 lb
Encryption	No	Yes
Hardening	No	Yes (nuclear event)
Anti-jam	No	Yes (antennal nulling and signal suppression)
Redundancy	Receive side: 4 for 2 (except earth) 3 for 1 (earth)	Avoid all single point failures Channels 1 & 2: 2 for 1
	Transmit side: 2 for 1 (earth & spot) 3 for 2 (otherwise)	10W TWTAs: 3 for 2 40W TWTAs: 2 for 1

[a]See INTELSAT V Satellite Specification (21 Sept 76).

[b]See Prime Item Development Specification for Defense Satellite Communications Systems, Phase III (DSCS-III) Satellite (30 June 80).

[c]Two or 6 channels may be grouped together as one 72-76 MHz or one 241 MHz channel with guardband used as part of super-channel.

Requirement Differences

Table E.2 shows that ISAT-V continues the trend for each succeeding generation of INTELSAT satellites to provide more capacity than the last. The ISAT-V antenna array has two global horns (one transmit and one receive), two hemispheric/zone offset-fed reflectors (one transmit and one receive), and two spot beam (transmit and receive) antennas. 6/4 GHz band communications use both the global horns and the hemispheric/zone multibeam antennas. The hemispheric beams are spatially separated (like the ISAT-IVA) and use right-hand circular polarization. The zonal beams, one within each hemisphere, use left-hand polarization. This allows four-times frequency use among the transponders attached to the hemispheric/zone antennas.

ISAT-V further increases its capacity by employing 14/11 GHz band frequencies on the spot beam antennas.

DSCS-III has evolved from DSCS-II in a different way. DSCS-III uses its complex multibeam antenna system for more reliable and secure communications. The receive multibeam antenna and its electronics can detect the location of a jamming signal and place a null over that source such that very little power from the jammer gets into the satellite to disrupt communications. The two transmit multibeam antennas can each selectively transmit up to 19 narrow beams, thus minimizing the area for signal interception. DSCS-III incorporates frequency-division multiple access and spread-spectrum digital techniques for interference resistance, not capacity enhancement.

DSCS-III has six main communications transponders: two with 40 watts of power and 60 MHz bandwidth; two with 10 watts and 60 MHz; one with 10 watts and 50 MHz; and one with 10 watts and 85 MHz.

An AFSATCOM single-channel transponder (SCT) provides a secondary communication subsystem on the DSCS-III. The SCT has its own UHF transmitting and receiving antennas, but also can be connected to the 8 GHz earth-coverage or main beam antenna receiving antennas. The SCT has some on-board processing capability: it demodulates the received uplink and remodulates it for transmission, and it can store messages for repeated transmission. The uplink has some protection against jamming.

Bus Differences

The DSCS-III bus has more severe requirements than the ISAT-V bus. It must maintain the same attitude control and station-keeping accuracy as ISAT-V, but with only 15 percent of the ground updates per year allowed to ISAT-V. DSCS-III is not intended merely to ride out a nuclear event and reinitiate communications at a later time; it must remain properly oriented and communicating *during* the event. The bus must protect the electronics from damage by such an event and its solar cells must survive.

Discussion

The many differences between the DSCS-III and the ISAT-V satellites precluded any useful analysis of the absolute cost consequences of each design and performance difference.

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